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VISUAL INFORMATION DISPLAY SYSTEMS

A SURVEY

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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Foreword

Visual information display systems connected to computers are fast becoming commonplace. They are found now in stock brokers' offices and schools as well as in jetliner control panels. The National Aeronautics and Space Administration and its contractors have developed and operated display systems of this type that can span nearly the whole spectrum of applications.

This survey of computer-related visual information display systems was undertaken for the NASA Office of Technology Utilization so that others may benefit from NASA's experience. The input-output capabilities of human beings, which determine the requirements for such systems, are likely to be much the same outside of the aerospace field as they are within it. This publication is intended especially for middle management personnel in areas in which the potential benefits from such modern technology have not yet been realized.

The report describes hardware and software with wide applications and explains the large-scale checkout and control systems used at the John F. Kennedy Space Center, the Marshall Space Flight Center, and the Manned Spacecraft Center. It also reviews findings in the Ames Research Center, the Jet Propulsion Laboratory, and other government and private laboratories. The reader is introduced to interactive display systems, simulation displays, and image enhancement techniques. Most of the examples cited are from aerospace work, but they were chosen because of their potentially broad utility.

This is one of a series of surveys through which the NASA Office of Technology Utilization is informing both public and private sectors of the economy of advances made in the course of the nation's exploration of space.

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Contents

Introduction

This publication presents selected examples of visual information display systems that may stimulate middle management to conceive ways in which present display technology can be applied increasingly to industrial problems. Most of the examples come from NASA projects, supplemented where it has seemed appropriate by industrial examples. Notably missing are military examples such the "L" systems of the Air Force; MTAC and NTDS of the Marines and the Navy, respectively; ARTOC of the Army; and dozens more. Some of these are fully described elsewhere, and most of them are similar to the systems selected for description here. Although it may be thought that most display technology is a spinoff from the television industry, it should be remembered that much of that industry has stemmed from military radar developments. Almost all of the hardware display developments in use today have descended from a military predecessor.

This survey was restricted to visual information display systems that are either computer-connected or updated with computer-generated information. It deals largely with console alphanumeric and graphic devices, including promising new developments. The scope of the study was exemplified by the field of cathode-ray tube (CRT) displays, which has figured in significant industrial advances. Such systems as files, exhibits, and printing were excluded from the study unless they were part of a specifically defined system. Also excluded were conventional typewriter or machine printout systems. Three-dimensional displays such as Holographic were considered too remote from practical application to be included in this report. Even with these restrictions, this survey covers a broad spectrum of displays.

To provide a suitable basis for understanding the examples presented, the first three chapters have been devoted to the three basic elements of a display system. Chapter I deals with human beings and some aspects of human engineering; chapter II deals with hardware and includes some recent NASA developments as well as general overview; and chapter III covers computer systems with the major emphasis on programming and the problems of software development. The remaining five chapters are devoted to applications.

There are many different potential applications for display equipment. For some of them, any of several currently available commercial display consoles are suitable. Some of the most promising applications are in on-line programming, design automation, process control, text editing, and source data creation.

Display system applications can be grouped into four broad categories that are summarized in table I together with examples of each particular system. These categories are reflected in the structure of this publication. The first category is monitoring, in which the user is primarily a spectator with perhaps a limited number of manual controls such as special pushbuttons, but not usually a keyboard. Chapter IV relates several prime examples drawn from the space effort. In the second category, engineering and design functions, there is a highly technical interchange between the user and the system and an interaction between man and machine; chapter V discusses interactive systems. Information storage and retrieval is divided into two categories—unstructured and structured files. The unstructured file systems are exemplified in chapter V because a considerable measure of user interaction is usually involved. Structured

TABLE I—*Potential Automated Display Applications*

Category 1—monitor functions

System operating monitors
- data processing installations
- automated systems
- airline arrival and departure systems
- checkout systems
- demonstrations

Paging systems
Security systems

Category 2—engineering and design

Engineering and mathematics
- research
- design
- development

Programming
- program development and debugging

Industrial and government management planning
- scheduling
- forecasting
- logistics

Category 3—information
Unstructured

Industrial and government management, planning and operations
- budgeting
- process control
- production control
- inventory management

Command and control (military)
- intelligence analysis
  - photo and map interpretation
  - cryptography and translation
- planning and war games

Text manipulation
Scientific research
- query and retrieval

Banking and finance
- credit analysis
- account analysis
- checking analysis

Structured

Hospital administration
- nursing stations

Transportation
- airline reservations
- auto rentals
- railroad car and shipment disposition
- fleet vehicle location and content control
- hotel and other reservation systems

TABLE I—*Potential Automated Display Applications*—Continued

Insurance
- policy search
- claim adjustment
- policy file maintenance

Banking and finance
- bank query stations
  - teller stations
  - management stations
- stock brokerage
  - portfolio analyses
  - stock quotations

Industrial administration
- personnel records
- financial administration
- group insurance files

State and local government
- vehicle license identification
- driver license file search
- traffic and criminal offense records
- deed search

Military administration
- base assets
- inventory control
- personnel records search
- maintenance status reporting and control
- force status

Education
- programmed teaching

Category 4—communication and simulation

Alphanumeric message transmission
- all applications presently being handled by communications printers

Critical message validation
Pictorial/graphical data transmission and enhancement
- publications
  - newspapers and magazines
- criminal photo transmission
- weather bureau information

Simulation

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file systems are reported in chapter VI. In these systems, the interaction is largely preprogrammed. The final category of communications and simulation is one in which a visual scene or message is processed or generated by a computer system for presentation to a viewer. Chapter VII covers computer generated images and movies, and chapter VIII covers image enhancement.

CHAPTER I

Display System Human and Task Dependent Parameters

The end toward which a visual display device is directed is the human being, who is demanding and limited in his visual function. Because display devices also have limitations, display systems are a compromise between the interests of men and the capabilities of the equipment.

The standards by which the performance of visual display equipment is measured are confusing at present. Terminology tends to be variable and inexact. For example, in the matter of resolution, one finds such measures as spot size, line width, white lines/inch, and optical lines; many units that are identical carry two or three common names.

Contributing to this hazy picture are the variations from man to man in activities and perceptions. A man may become more tolerant of flicker as he grows older but be less tolerant to poor contrast as he becomes tired. He responds to low light levels with one set of receptors and perceives color with another. He does not present dependable performance.

There is obvious need for standardization of equipment requirements. The standards must determine which requirements matter, how they should be measured, and in what units they should be expressed. Similarly, human beings should be more adequately defined in terms of normal ranges of behavior and under what precise conditions that behavior should be measured. Both necessities present difficulties because some of the functions are not easily reduced to objective measurement.

HUMAN DEPENDENT PARAMETERS

Photometry

The essence of visual display is creating a light signal within the physical world and passing it into the psychological world of the human. The physicist thinks of light as radiant energy, with wavelength and spectral distribution; but many men prefer to speak about brightness, hue, and saturation. Photometry attempts to mediate between these approaches by establishing average characteristics by objective measurement, if possible, without involving the observer.

The physicist measures the radiant energy emitted by a radiant body, but the eye is limited to a small range of wavelengths and responds differently to each different wavelength. Psychological brightness is called luminance or luminosity; a plot of luminosity against wavelength produces a bell-shaped curve with a maximum in the green. The retina, with its two kinds of receptors, actually possesses two curves of luminosity, one for the cones (photopic) in the center of the visual field and the other for the rods (scotopic) at the periphery. The rods are slightly more responsive to the shorter wavelengths.

Brightness and Contrast

Brightness is the measure of light intensity of the signal and contrast is the relative brightness of the signal over the brightness of its background. The ease with which information can be read is directly related to contrast, but the required brightness is affected by the size of the object area. If the size is decreased, the brightness must be increased. Duration also affects brightness: short flashes must be brighter than long flashes. Below durations of 0.1 second, however, isolated flashes of equal energy are equally visible. Brightness is commonly measured in units called foot-lamberts. Typically, brightness ranges from 20 to 100 foot-lamberts. Still lower light levels call for dark adaptation, but too low a light intensity causes a shift from the cone to the rod receptors with a concomitant and severe reduction of acuity.

Two definitions of contrast are in general use. One is called contrast ratio; it is the ratio of the brightest to darkest portions of the display. It finds application where the gray scale is significant as in television. The other contrast is called percentage contrast or brightness contrast. The brightness contrast is equal to the image brightness minus the background brightness divided by the background brightness. The percentage contrast is equal to the brightness contrast multiplied by 100.

Still another contrast is that of color. Although brightness contrast is far better for detail, color contrast may be used for indicating classes of information or for enhancing contrast in marginal situations. For example, the afterglow of long persistence phosphors has a large component of orange in it. The contrast can be enhanced by using a blue ambient lighting, provided the marked contrast does not produce psychological reactions.

Resolution

Resolution is a measure of discrimination within fine detail. Resolution depends partly upon the visual acuity of the eye and partly upon the resolution of the display itself. The resolution of the display depends upon the size of the image-creating element—the bluntness of the "pen" that draws the display and the graininess of the web upon which the display is spread out. Other factors include positioning accuracy, registration, and image diffusion.

The visual acuity of the human eye depends upon several variables. For example, one can measure the stereoscopic acuity to determine the minimum stereoscopic displacement the eye can resolve. For most visual display devices, there is no need to consider this ability. On the other hand, vernier acuity may be significant because it is the measure of how close an operator can bring an indicating needle into alignment with a dial mark. The eye can perform this operation with surprising accuracy, depending on contrast, brightness, and the length of the needle or line. Typically, vernier acuity is between 1 second and 1 minute of arc.

The chief type of visual acuity important to the field of visual display devices is the minimum detectable acuity. Here one deals with the minimum detecting sensor in the eye, namely the cone. In general, the cone can resolve about 1 minute of arc. But several situations change this limit. For example, if one tries to detect a single spot of light within a dark background, it is sufficient for the spot to trigger only one cone: the human will recognize the spot of light. The spot in this case may be considerably less than 1 minute of arc when it is bright enough. But conversely, a single dark spot in an otherwise bright field has to be at least 14 seconds of arc before it can be detected.

Flicker

Cathode-ray tube displays must be "refreshed" periodically to produce a persistent display. The rate of refreshment is a function of several factors in addition to the persistence of the particular phosphor in use. The decay in phosphors is typically exponential. Medium decay times are of the order 1 to 100 milliseconds; there are phosphors with decay times in the microsecond range, and one slow phosphor lasts 16 seconds. The problem of flicker in the display is to provide a repetition rate such that the viewer effectively sees a flickerless image.

Flicker is more noticeable when the brightness is greater. Thus brightness can be plotted against repetition rate to indicate minimum rates for no flicker. In general however, 50 to 60 repetitions per second seems to be a safe lower limit.

Lower repetition rates are not totally unusable, however, because operators are not necessarily bothered by a small amount of flicker. There is greater tolerance to flicker by older operators. The only flicker rates to avoid are those in the 10- to 15-Hz range at which the flicker is most objectionable. Probably there is a relationship between this repetition rate and the alpha rhythm of the brain. It is known that flicker frequencies in this range may induce epileptic seizure in those who are susceptible to it.

Readability

Readability is a characteristic of type faces and has been a concern of the printing industry for a long time. For the English alphabet and Arabic numerals there are several variables that affect readability. Sharp-pointed corners on the symbols tend to make for greater readability than rounded corners. The height-to-width ratio should be about 3 : 2 to 3 : 4 for optimum legibility. Similarly, the line widths should be $\frac{1}{30}$ to $\frac{1}{40}$ of the heights. The ratios minimize the blurring and fusion at a distance.

Many methods of generating characters do not yield the best possible shapes. As a result, confusion can arise between similar shapes such as 5 and S, and 2 and Z. When economy somewhat degrades characters, the images can be improved by making them larger on the display.

Visual Fidelity

In applications in which a display device depicts a graphical situation, the system is required to meet certain standards of fidelity. One of the distortions in the cathode-ray tube is the pin cushion effect. Another, caused by a non-linear sweep can stretch or shrink one side or the other so that all parts of the image do not appear to the same scale. If the display is geographical, the fidelity must be at least good enough to depict the relation among objects on the terrain truly in the display.

TASK DEPENDENT PARAMETERS

Several parameters of a visual display system are determined by the nature and requirements of the task. Table II lists typical characteristics of display consoles in various applications.

Screen Size

The most important considerations in determining screen size are the size and geometric disposition of the audience, the format and quantity of information to be displayed, human visual limitations, and the availability of display hardware. The screen size should be consistent with the volume and detail of data required, who will use the data, and how it will be used.

Message Size

The message size is a function of the task and of the human being. The size should not be greater than the viewer can successfully comprehend and utilize. The resolving power of the system also places an upper limit on it.

Message Format

Many types of information can be displayed in visual devices. Besides alphanumeric and symbolic characters, there are vectors, points, views of map outlines, grid lines, curves, and area shading. Some data are orderly, as in tabular work; other data are random, as in maps. The data may be digital, as with vectors, or they may be scanned (continuous), as with TV. There are also overlays and other combinations of two or more independent image sources. When the display operates in conjunction with a computer, it ought to be able to accept data for display in digital form.

The degree of freedom of placement and organization of the data on the screen affects the bandwidth requirements and the cost of the equipment. A fixed format is one in which the various items appear in predetermined positions; free or random placement allows the information to be positioned as a function of time or significance. Greater freedom of placement brings higher costs.

Coding has advantages. Color is one method of coding, but most display devices are monochromatic at present. Symbols are another form of coding. Carefully drawn outlines of ships, planes, and guns may be more quickly recognized than the spelled-out equivalent English words. Shape recognition tests indicate that with practice a human being can recognize between 200 and 2000 different shapes.

Quantity of Information

This parameter is a function of the task to be performed, the ability of a human operator to comprehend and utilize information, and the

TABLE II.—*User versus Desirable Characteristics*

User	Number of characters	Number of fonts	Character repertoire	Special inputs (light pen, video, etc.)	Special outputs (hard copy, etc.)	Plotting capability	Screen size, in.	Color
Design engineers and mathematicians	≈5000	1	Alphanumeric and symbols	Yes	Maybe (1 per x displays)	Yes	≈20	Probably
Program designers	At least 2000	1	Alphanumeric and symbols	No	1 per x displays	No	14	No
Industrial/Government Management Personnel								
Budgeting	2000	1	Alphanumeric and symbols	No	1 per x displays	Bar graphs & tables only	14	No
Process control	500	1	Alphanumeric and symbols	No	1 per x displays	Bar graphs & tables	14	Desirable
Production control	500	1	Alphanumeric and symbols	No	1 per x displays	Bar graphs & tables only	14	Desirable
Inventory management	1000	1	Alphanumeric and symbols	No	Yes	No	14	No
Military commanders								
Photographic and map interpretation	5000		Alphanumeric and symbols	Yes	1 per x displays (low x)	Yes	20	Yes
Cryptography and translation	2000	More than one desirable	Alphanumeric and symbols	No	1 per x displays	No	14	Desirable
Planning and war gaming	Max. pos-possible (5000 ok)	1	Alphanumeric and symbols	Cursor, light pen	1 per x displays	Desirable	20	Yes
Scientific research engineers	1000	More than one	Alphanumeric and symbols	No	1 per x displays	No	14	No
Banking and finance specialists	1000	1	Alphanumeric and symbols	No	No	No	14	No
Hospital administrators—nurses	≈500	1	Alphanumeric and symbols (≈ 125)	No	1 per x displays (perhaps 1 for 1)	No	10 or 14	No
Airline reservations clerks	500	1	Alphanumeric and symbols	No	1 per x displays	No	10	No
Auto rental dispatcher	500	1	Alphanumeric and symbols	No	1 per x displays	No	10	No
Railroad car and shipment disposition controllers	1000	1	Alphanumeric and symbols	No	Yes (1 per x displays)	No	14	No

Fleet vehicle location and contents controllers	1000	1	Alphanumeric and symbols	No	Yes	No	14	No
Insurance company managers and clerks	1000	1	Alphanumeric and symbols	No	Yes (1 per x displays)	No	14	No
Bank tellers	500	1	Alphanumeric and symbols	No	No	No	10	No
Bank managers	1000	1	Alphanumeric and symbols	No	1 per x displays	No	14	No
Stock brokers								
Portfolio analysis	1000	1	Alphanumeric and symbols	No	1 per x displays	Bar graphs and tables	14	No
Stock quotations	500 max	1	Alphanumeric and symbols	Np	No	No	10 or 14	No
Industrial administrators (personnel records, group insurance files, financial administration)	1000	1	Alphanumeric and symbols	No	1 per x displays	No	14	No
Librarian (library search)	1000	1	Alphanumeric and symbols	No	1 per x displays	No	14 to 20	No
Text editor	500	1	Alphanumeric and symbols	Mo	No	No	14	No
Librarian (indexing and abstracting)	5000	Several fonts	Alphanumeric and symbols	No	1 per x displays	No	14 to 16	No
Military administrators	1000	1	Alphanumeric and symbols	No	1 per x displays	No	14	No
Utilities, telephone service representative	500	1	Alphanumeric and symbols	No	1 per x displays	No	10	No
Educators	1000 (at least)	1	Alphanumeric and symbols	No	No	No	14	Not necessary
State and local government personnel (vehicle license identification, traffic and criminal office records)	500	1	Alphanumeric and symbols	No	1 per x displays	No	10	No
System operators, monitors, paging clerks, security personnel	500	1	Alphanumeric and symbols	Video	1 per x displays	No	14 to 20 or more	Perhaps
Communications								
Message center operator (alphanumeric)	5000	2	Alphanumeric and symbols	Special devices (Maybe)	1 per x displays	No	14	No
Message center operator (pictorial, graphical data)	5000 or more	1	Alphanumeric and symbols	No	1 per x displays	Yes	20 or more	Yes

type, format, and rate of data presentation. A large quantity of similar information grouped by logical category and statically displayed can be comprehended more easily than the same amount of disassociated, randomly presented, and rapidly changing data. The quantity of information displayed on a screen should be considered in terms of the function of the information tempered by the ability of the human operator to utilize the information.

Response Time

Response of a visual display system is found in three modes of operation: tracking, updating, and replying. In the case of tracking, response time is measured by the time required to display the current situation. Certain display methods have inherent delays in their principles of operation; others are nearly instantaneous in response.

The response time for updating is measured by the time required to present fresh data on the display. The response time for replying is met in question and answer situations. How long does it take to get a response after the operator places a query? This response time should be less than a second; it has been found that after longer response times the operator has become bored or has forgotten his question.

Erasability

Erasability is a measure of the ability of the system to expunge data. Some systems can be said to erase data instantaneously; other systems have persistence that makes instantaneous erasure impossible. Some systems have selective erasure in which only specific parts of the display are erased. The task determines the erasure requirements.

Color

The development of the color TV tube has aroused hope for the inclusion of color in non-TV applications. The upper limit of consistent human discrimination is between 10 and 12 different colors, but the present color display generation methods do not guarantee much better than six or seven distinguishable colors.

Color raises the problem of registration (i.e., the accuracy with which colored areas bound each other). If registration is important, the upper limit of the number of different colors should be four.

Half-tone

The ability of a display system to generate distinguishable levels of gray is called its half-tone capability. The term is borrowed from the printing industry in which gray scale is approximated by modulating the size of regularly placed dots so that the integrated area of the black dot and the white background resolves in the eye as a degree of gray.

No formal method exists for measuring gray scale, although there is both an objective and subjective aspect to the measurement. Objectively, a factor of 2- or a 3-db luminance can be called one half-tone level. Subjectively, humans can determine a half-tone level as the smallest noticeable increment of change in brightness. For contrast ratios of 10:1, there are about 10 discernible shades of gray. The typical TV display has 5 to 10 levels of discernible gray scale. Most display systems, however, operate in a binary fashion in which contrast is the major factor.

HUMAN BEHAVIORAL ASPECTS

Because the purpose of all visual display devices is to inform a human being, studies of human beings as they react to display devices can lead to new understanding of the relationship. Some studies in this area have been made; more are needed in several areas to gain better answers. So far the investigations have not produced much more than intuition would have indicated. Nevertheless, some observations have been made that should help in display device designing.

One of the major problems is the highly adaptable nature of a human being. If he is given a device to watch, he tends to accommodate and adapt to the particular qualities of the device. This adaptivity may make even a poor situation acceptable. But the same adaptivity makes it difficult to measure the human parameters. Research results generally indicate maximums and minimums. The human being remains the least understood part of display systems.

One of the questions that has not been adequately answered is the relative value of various modes of presentation: visual, auditory, and tactile. Visual presentation has been the most widely used mode. Auditory has found some applications, such as in navigation, in which the guidance signals once were fed to pilots through earphones. There is no evidence to indicate that auditory is any better or worse than visual, provided the number of independent variables does not exceed two. Pitch and interval, for example, are about all the variables a normal human being can distinguish reliably. If volume becomes variable, the pitch determination becomes poor. Tactile input has barely been tried.

The size of a display seems to have no effect on performance except at the most exaggerated extremes. Strangely, a circular display seems to be more easily handled than a square one.

The speed of presentation, as intuition would indicate, is inverse to comprehension: as the speed of presentation increases, the comprehension of the data goes down. When following a moving point, however, the human being operates more with a phase angle lag than with a frequency or amplitude error even as speeds increase.

Brightness, also as one would suspect, has a broad range of values within which the adaptive human being is able to succeed. In dim light perception tends to fall, and extreme brightness is tiring. Tests, therefore, tend only to reveal the limits between which the behavior of the human being is satisfactory rather than to indicate optimum points.

In nearly all man-machine interfaces some training is required before achieving best performance. But training, it must be remembered, is in reality only taking advantage of the human's adaptivity and effectively changing him to suit the equipment. Indirectly, then, one might think in terms of designing equipment so as to minimize the training required. In such a circumstance, some "optimum" point may have been discovered that could indicate more specifically the details of the human's behavior than the mere discovery of the outer limits and thresholds of his sensory apparatus.

One of the present fields of study is eyeball motion. In typical tests, equipment is placed on

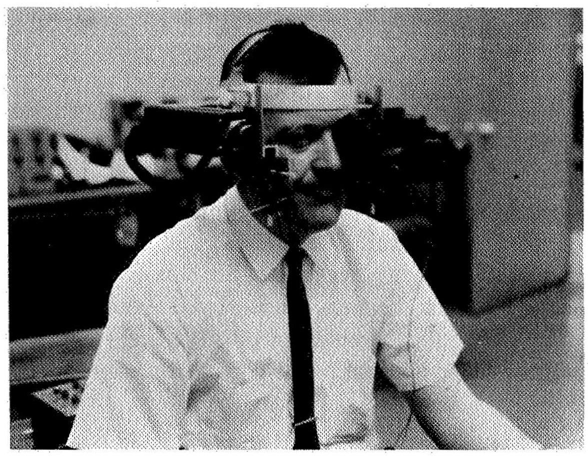

FIGURE 1.—Eye motion analysis. The individual is being tested to determine how his eye movement reacts to a display. On the left is a small television vidicon camera that shows the area at which the subject is looking. On the right is a device that shines a light on the subject's eyeball and picks up the reflection that is superimposed on the field of view seen by the TV camera.

FIGURE 2.—Eye motion analysis equipment. The mechanism of figure 1 is shown on a dummy in this illustration. The output of the mechanism is transmitted to a television monitor that shows the field of view of the subject and a spot of light on the field of view pinpointing where the subject is actually fixing his gaze. On the right is a TV tape recording mechanism for permanently recording the results of the experiment.

the head of the subject to meaure the eyeball and head motions. The subject is then required to assimilate data displayed on a screen. Hopefully, information may be gained about the methods that various subjects employ when presented with, for example, a large screen full of various data. Is there an orderly routing or is it a purely random scanning? Figures 1 and 2 show the Eye Motion Analyzer at Griffiss Air Force Base in New York. Future studies will examine the effects of color, density, update time, contrast brightness, size, lack of information, and other effects that presumably influence a subject's capability to handle information presented to him by visual display devices.

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CHAPTER II

Display System Components

INTRODUCTION

The designer of a visual display system has a variety of components available from which he can build his system. Some of them offer him stability of characteristics and reliability of performance. Other components offer new possibilities, provided he is tolerant of limitations inherent in unproven techniques.

The principal device on which most visual display devices depend is the cathode-ray tube (CRT). The impetus of commercial television, plus advances in understanding brought about through semiconductor research, has pressed the development of CRTs that offer the designer excellent performance in black and white and good performance in color. Performance in both cases includes various degrees of qualities in resolution, brightness, contrast, and cost. Special variants of CRT-type devices now are finding limited application in the general field of visual display devices.

Television is based on the elemental CRT. Many display applications are completely satisfied by standard commercially available TV sets. Similarly the vidicon television camera serves as the basic input device in many applications. The linking of TV to digital computers, however, has created the digital television system in which the continuous scan of the ordinary raster is replaced by dot structures. There are numerous hybrid developments that make use of readily available equipment and add specialized devices to solve some particular problem or serve some special purpose.

There are limits to the CRT, notably when large-screens displays are required. So other techniques are being actively investigated to display data to a large audience or at more than usual distance.

For an interactive system, the designer requires a variety of input devices. Basically, such devices perform the same functions as pencils and pens and such common input tools as control levers and keyboards. When used as input devices they provide an input signal to the system. The system in turn feeds back a signal to the operator that indicates what he has done.

CATHODE-RAY TUBE

A wide variety of cathode-ray tubes has been developed to fill the needs for display devices ranging from home television sets to airborne radar systems. The CRT has three parts, a controllable source of electrons or cathode rays, an electron optical section, and a screen or target.

Cathodes

The electron source in a cathode-ray tube is called a cathode, hence the name cathode rays. In the original work on cathode rays by Sir William Crookes, the cathode was a cold metal electrode. It was shortly found that a heated metal surface provides a more copious supply of electrons per unit area of cathode, but power is consumed by the cathode heaters and hot cathodes are shorter lived than cold ones. Efforts to improve cathode power consumption, life, and electron emissivity have continued for more than 50 years.

The surface properties of electron emitters are subtle. At one time large numbers, and sometimes entire production runs, of vacuum tubes were discarded because the cathodes mysteriously refused to function. It is now realized that minute traces of surface contaminants can damage a cathode. A theoretical understanding of effects such as this has come from research in solid-state physics, and it is now possible to predict, at least in a qualitative way, the per-

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formance of some cathodes. Even so, much of the technology remains empirical in nature. Recent research in cathodes falls into four areas: cold cathodes, nonstoichiometric compound thermionic cathodes, oxide cathodes, and pure metal cathodes.

Cold cathode developments are based primarily on the application of III–V compound semiconductors. These are compounds formed from elements having three and five valence electrons, respectively, which, when crystalized, have properties similar to the valence four elemental semiconductors silicon and germanium. When the bulk material is given a thin surface coating of a metal such as platinum or tungsten, a deformation occurs in the electron energy bands at the surface that so lowers the electron affinity of the cathode that room temperature electrons are energetic enough to cross the surface. Examples are gallium phosphide coated with platinum or tungsten (GaP/Pt or W) and gallium arsenide coated with cesium (GaAs/Cs).

Nonstoichiometric compounds are those in which the elemental fractions by weight do not permit formation of pure compounds. In the crystalline state such compounds have properties so distinctly different from the pure compounds that the same elements may form in different ratios. This situation is somewhat similar to that of some binary alloys with a lower melting point than either constituent. In the case of nonstoichiometric alkaline tungstates deposited on tungsten (Sr_3WO_6–$SrWO_4$/W), low surface work functions promise high current densities of the order of 100 amperes per square centimeter. This current density is several orders of magnitude better than is commonly achieved. Long cathode lives have been achieved (9000 hours), but only with careful exclusion of gases.

The conventional cathode is a triple oxide on nickle (BaO, SrO, CoO). Current densities of 1 ampere per square centimeter are about the limit with conventional structures. Recent work has raised this level to 6 amperes per square centimeter in special cases. Lifetimes of the order of 1500 hours have been obtained with current densities in excess of 1 ampere per square centimeter. These values, however, apply to triode structures only.

The stimulus for research into the pure metal cathode is the thermionic converter. This is a device to convert heat energy into electrical energy. Tungsten wire coated with mixtures of tungsten or tungsten carbide, thorium, and zirconium provide current densities up to 30 amperes per square centimeter. Temperatures range up to 1600° C but if lanthanum is substituted for thorium, temperatures as low as 1400° C are sufficient. These cathodes last as long as pure tungsten ones.

Electron Optics

The electrons emitted by the cathode are formed into a beam, focused, and then directed to a target by combinations of electric and magnetic fields. Most cathode-ray tubes employ one of two simple deflection and focusing systems to direct the beam to a chosen spot on a screen. One is the magnetic system commonly found in the television receiver and the other is the electrostatic system commonly found in laboratory oscilloscopes. The tubes in display applications sometimes employ more complex systems. Several such are described below when specific devices are considered.

Electrons tend to move parallel to an electrostatic field towards the positive electrode. Moving electrons tend to curl around magnetic flux lines. Consequently, to deflect an electron beam in the vertical direction a vertical electric field is required or, alternately, a horizontal magnetic field. There are various advantages and disadvantages to each system in any particular application. Thus, the magnetic system favored in television provides as a byproduct the high accelerating voltage required to generate the electron beam. On the other hand, the electrostatic system is inherently easier to operate at high speeds, which is one reason it is used in laboratory equipment.

Cathode-Ray Targets

The most common cathode-ray target or screen is simply a cathodoluminescent phosphor coating on a glass faceplate. Light is produced wherever electrons strike it. Another example is the shadowmask color tube screen. In this device a regularly perforated screen shadows an array of phosphor spots. Each perforation has three spots associated with it to produce the three primary colors required for a color picture. The geometry is such that the spot selected, and hence the color, depends only on the direction in which the electron beam passes through the shadowmask. Less familiar are the targets used for storage tubes and image converters. These are covered in a later section.

Phosphors

An enormous amount of work is carried out each year on phosphor research. One manufacturer (Sylvania) advertises that its investigators synthesize and test 50 000 new phosphors annually. Such a program is concerned with all the possible excitation modes of the phosphor including X-rays and ultraviolet light. Out of the 50 000 only a few cathodoluminescent phosphors will be found of significant worth and put to use. To collect phosphor information, the Joint Electron Device Engineering Council (JEDEC) distributes a publication (16A) on the optical characteristics of CRT screens. Manufacturers may register phosphors by meeting certain requirements. It is usually possible to obtain any special CRT with a chosen registered phosphor.

Registered phosphors are given "P" numbers. P–4 is the standard black and white television phosphor. P–22B, P–22G and P–22R are blue, green and red color television phosphors. A registered phosphor may be a mixture of phosphors as is the case with the P–4 phosphor. In this case, the component phosphors may have National Bureau of Standards code numbers. Thus, NBS 1020 is the code number for the blue component of the all sulfide P–4 phosphor. Standard phosphors are available from the National Bureau of Standards.

Phosphor research is concerned with the production of phosphors with specified properties such as color or persistence. Conversion efficiency is also a concern. Only a few phosphors, all sulphides, exhibit efficiencies in excess of 15 percent. Recent research in visible phosphors has been based almost entirely on rare earth activated host crystals such as europium—activated oxides or oxysulfides. New ultraviolet emitting phosphors, useful for dry film recording, have been found among the lead activated silicates. One of these is more than twice as efficient as the best previously available UV phosphor, P–16.

SPECIAL CATHODE-RAY TUBES

New cathode-ray tube developments are announced daily and it is not feasible to cover them all here. We have chosen to describe briefly some of the NASA–sponsored developments in this area. Much of the material in this section was discussed at a seminar open to industry on Recent Advances in Display Media, sponsored by the Electronics Research Center of NASA.*

Single Gun, Two-Color Tube

A recent development is the use of non-linear cathodoluminescence to produce color variations. While most phosphors exhibit a linear relationship between beam current and light output, a number have been found for which the response is non-linear. If a phosphor having a relatively strong, high-current response and weak low-current response is mixed with a different phosphor producing different colored light and having the opposite current response, a color variation may be obtained with beam current. If a green non-linear phosphor is mixed with a linear red phosphor, the color will shift from red at low current to yellow-green at high current. Development of a tube based on this principle is being carried out under NASA sponsorship by ITT Industrial Laboratories.

Optical Diode Faceplate

Frequently a cathode-ray tube must be used in conditions of highly variable ambient light. A radar screen in a lunar excursion module or an aircraft cockpit, and a television set on a beach, present similar problems of contrast. No good black cathodoluminescent phosphors are known and a black pigment absorbs emitted

*These proceedings have been published as NASA SP–159.

light as well as ambient light. Some partially successful, high-contrast developments have been based on transparent phosphors. A new development is the optical diode faceplate (fig. 3) developed by Hartmant Systems Inc., under NASA sponsorship.

The optical diode faceplate is a four-layer device. The first layer is a cathodoluminescent ultraviolet emitting phosphor. The second layer is an ultraviolet transmitting black filter. The third layer is a transparent, visible emitting phosphor that is activated by ultraviolet light. The fourth layer is a transparent ultraviolet absorbing filter. Ultraviolet light from the first layer passes through the second layer into the third where it is converted into visible light and passes through the fourth layer to the viewer. Ambient light passes through the fourth and third layer and is absorbed in the second, while ultraviolet light, which might excite the third layer, is absorbed in the fourth. If desired, a quarter wave coating may be given the glass to reduce reflections. To the observer, the screen appears black and excellent contrast is obtained even in direct light. (fig. 3.)

Thermochromic Cathode-Ray Tube

Thermochromic materials exhibit a marked color change when the temperature passes through a transition range. When such materials are used in a cathode-ray tube, the energy supplied by the electron beam is sufficient to cause a color change. One experimental tube employs a mixture of thermochromic material with a conventional phosphor to provide a display visible under extremes of ambient lighting. Thermochromic cathode-ray tubes may provide an inexpensive, large-screen projection system, if problems of resolution and response time can be solved.

Direct-View Storage Tubes

The direct-view storage tube provides one solution to the problem of regeneration encoun-

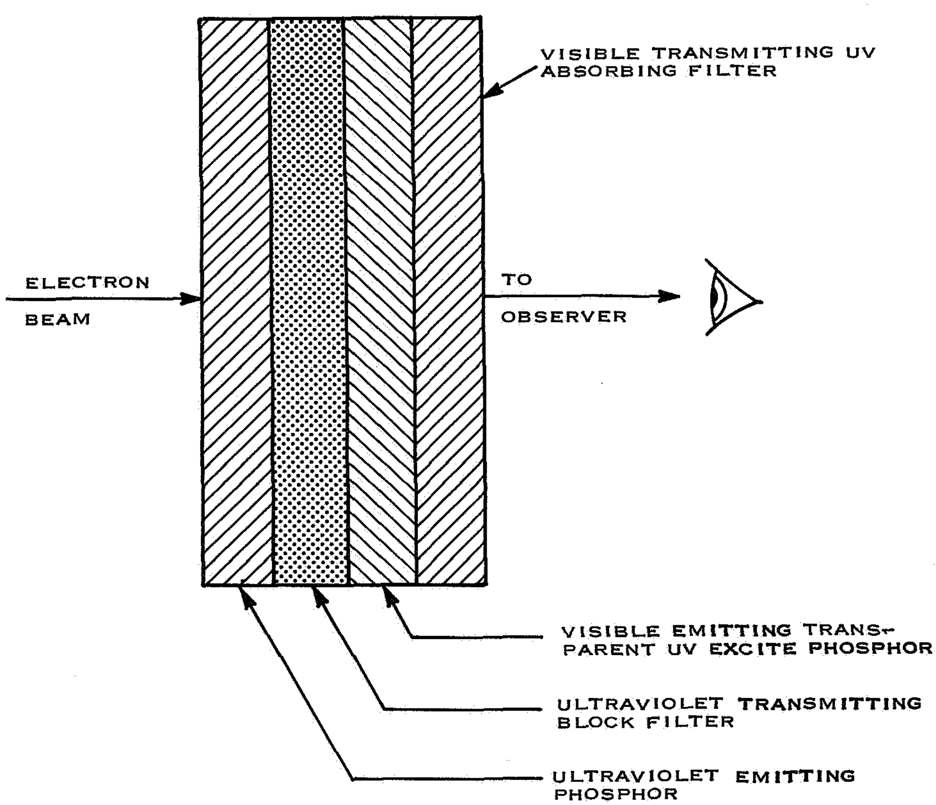

FIGURE 3.—Optical diode faceplate.

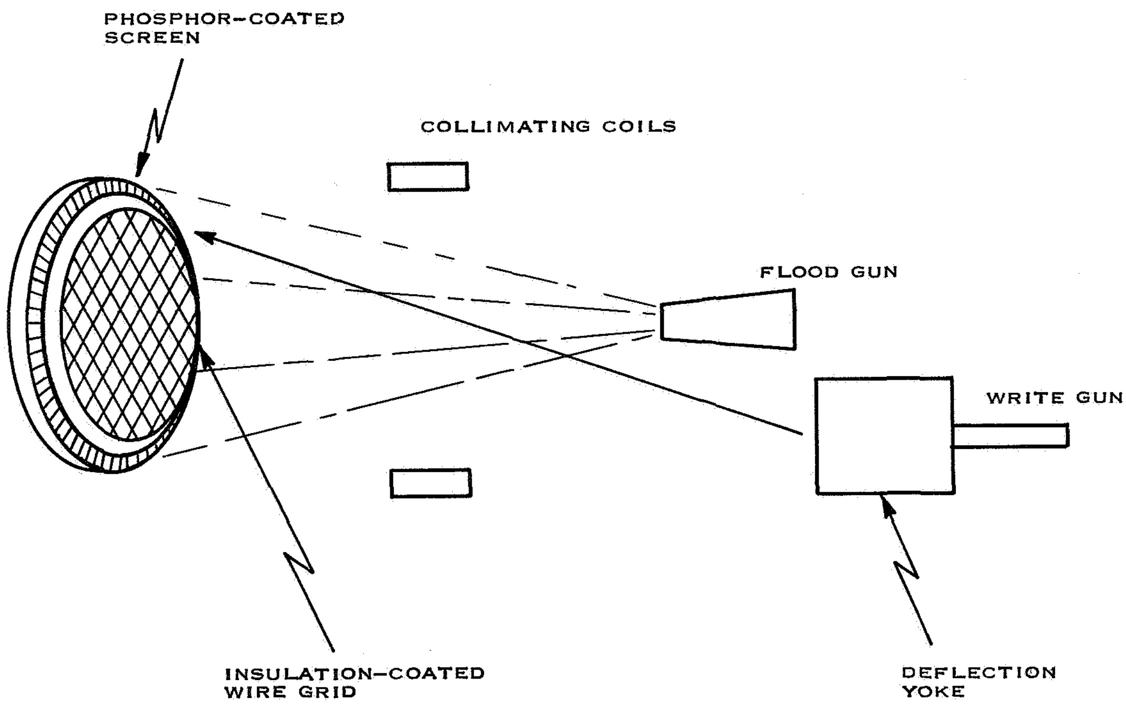

FIGURE 4.—Direct view storage tube.

tered in the use of cathode-ray tube displays (fig. 4). In the conventional cathode-ray tube, the electron beam is directed against a phosphor-coated screen with a resultant prompt production of light. The only storage is phosphorescence if a long persistence phosphor such as a P–34 is selected. The lifetime of such an image is measured in seconds and brightness is at a minimum.

A direct-view storage tube, typically, contains two electron guns and an insulated metal grid. One of these, the write gun, is provided with a deflection system so that the beam of electrons can be positioned in the conventional manner. The other gun provides a high-current, low-energy electron beam that, if permitted by the storage grid, is sufficient to illuminate the viewing screen uniformly at high brightness over its entire surface. The storage grid modulates the electron flood. Electrons from the flood gun are collimated to fall perpendicularly to the grid. Where the grid is negatively charged, the electrons are repelled and cannot pass through. Where the grid is relatively positively charged, electrons can reach the screen. The grid is sufficiently negative at all points to prevent flood gun electrons from ever reaching it.

To erase the image, the metal grid is raised to a positive potential so that flood gun electrons are attracted to the insulation until no more charge will collect. The original charge distribution is thus erased. A negative pulse then is applied to the grid which, because of the accumulated negative charge, becomes negative and entirely blocks flood electrons from reaching the screen.

Images are painted with the write gun in a conventional manner. The energy of the write-gun beam is currently controlled so that when directed at the negatively charged grid, it has sufficient energy to reach it and cause secondary emission of electrons. The areas written upon, therefore, become relatively positively charged and flood gun electrons can pass through the grid.

Scan Converters

The storage-tube principle may be applied to the problem of scan conversion. In this type of operation, an image written on a grid by stroke writing or shaped-beam techniques may be scanned out in the form of a television raster. It is also possible to convert radar images or different scan or raster systems into standard form presentable in inexpensive television monitors.

When used as a scan converter, the tube is altered by replacing the electron flood with a scanning beam. The beam is detected as it penetrates the grid. In some cases only a single gun is required. For radar conversion, a two-gun coaxial geometry is often used. The grid is placed in the middle with a gun on each side pointing in opposite directions. This arrangement allows continuous operation of both beams and simplifies the use of magnetic deflection for the radar image.

SYMBOL GENERATORS AND VECTOR GENERATORS

The cathode-ray tubes described in the previous section require electronic control and, in most cases, storage of information in order to form an image. In this section some of the more common ways in which this is accomplished are described. In many systems one or more methods may be combined. Occasionally, two or more guns may be contained within a single envelope. More commonly, a single gun is time-shared. For instance, if the primary image is a radar picture with a slow sweep, the beam may be borrowed for a few microseconds at intervals in order to draw vectors or symbols.

Dot Matrix Character Generation

Dot matrix characters are commonly used with discrete arrays of elements. They are commonly seen in advertising displays and race-track odds boards. Characters are formed by selection of data from a rectangular 5×7 or 7×9 array of dots. Smaller arrays are sometimes used when only a few symbols are needed. In the case of discrete displays, each dot is represented by an active element such as an incandescent light bulb. Each element is usually connected to a switch (electronic or mechanical) that is controlled by a perforated tape or manually.

When employed with a cathode-ray tube, the dot matrix system first positions the beam to the character location and then moves it incrementally and allows it to dwell on each spot position in the array in a definite sequence. The sequence may be controlled by electronic counters. For each spot position, the character generator contains a storage unit containing a single storage bit for each symbol to be displayed. The character code supplied by the information source is decoded to select the correct storage bit, and the information content determines whether the beam should be turned on. Dot matrix characters tend to be less well formed than those of other methods, although this is more a matter of practice than of principle.

Stroke Generators and Vector Generators

In the stroke-writing technique, the beam is positioned initially and then allowed to move in short straight line segments from one selected position to the next. Voltages to position the beam are established by a counter-selected resistor or diode elements that apply new X and Y voltages to the deflection circuits. A third resistor determines whether the beam should be on or off. In this method, a different set of resistors or diodes must be selected for each different symbol produced.

In a variation of the above technique that is sometimes encountered, the beam follows a fixed route with selected segments being switched on in transit. With this technique the expense is reduced, but the method is slower and the character poorer than with the independent method.

Monoscope Character Generator

The monoscope is a special cathode-ray tube that contains a target anode. The anode is printed, engraved, photo-etched, or inlaid with a character font usually arranged in a square array. The electron beam is indexed to the position of the selected character and then low-amplitude, high-frequency X and Y scanning voltages are applied. Secondary emission from the character is detected to produce a video signal.

In use with a display tube, the display beam is indexed to the desired position, often with magnetic deflection, while the X and Y scanning voltages electrostatically perturb the beam position in synchronism with the monoscope beam. Character formation with the monoscope is excellent and any desired character may be formed easily.

Shaped-Beam Tubes

Shaped-beam tubes produce characters by passing a broad collimated electron flood through a mask for character formation and then deflecting the beam to the selected location. Deflection systems are required first to select the mask opening; then to compensate for this deflection and correctly position the beam on the screen. Good quality results are obtained. The shaped-beam tube has found considerable application in television systems, photographic recording systems, and hard-copy generators.

STORAGE UNITS AND REGENERATION

Except for storage tubes or photographic recording systems, the information displayed on a cathode-ray screen must be continuously refreshed from a storage device. The uniform image observed by the viewer depends upon persistence of vision and to some extent phosphorescence of the screen, while the electron beam is time-shared among all the symbols or picture elements present.

The basic repetition rate depends upon the factors of brightness and background illumination among other considerations. The commercial television frame rate is 30 frames per second, interlaced two to one. Close examination reveals a noticeable flicker in many cases on the individual lines, although observation from a distance conceals it. To avoid flicker, a character generator must be supplied with data at a sufficiently high rate from the storage unit. The amount of data required depends on the system.

Symbols may be plotted in a specified location in which case position coordinates must also be supplied. This practice is common in radar applications when only a small amount of information may be plotted. When the primary display is textual information, it is common to maintain one-for-one correspondence between memory locations and screen locations. In this case, coordinate information is not required.

Computer-connected display systems require storage separate from that provided by the computer whenever the display access requirements adversely affect computer performance or when remote communication problems limit the access rate. Display consoles used in airline reservation systems or in stockbrokers' offices commonly have storage units of a few hundred characters and communicate over ordinary telephone lines. Acoustic delay lines may be used to provide the storage. In some cases where several consoles share a common comunication line, a common magnetic core storage unit is provided. The display storage unit sometimes serves as a message buffer unit for printers or for input keyboards when two-way communications are involved.

TELEVISION SYSTEMS

At the NASA Manned Spacecraft Center in Houston, an extensive closed-circuit television system provides the operators of the Mission Control Center and supporting groups with an extremely flexible information system. Static and dynamic data are optically mixed and the combined image is transmitted by means of television to a television switching matrix. In addition, TV cameras monitor line printers, XY plotters with launch data, and teletype equipment carrying data such as weather reports and status of recovery forces. Commercial television and other live-action television is supplied to the system as well.

Television also monitors activity in the computer room, particularly by remote operators, to determine which tape handlers or other peripheral devices are in use during program debugging.

Digital Television

The term digital television refers to the presentation of an artificial digitally composed television raster. Each TV line is divided into a specified number of picture elements and a bit of storage is provided for each element. The storage bits are accessed sequentially in synchronism with the television sweep to present a picture.

Storage units for digital television typically are either magnetic drum or magnetic core storage. The core units offer the advantage that picture composition may be carried out readily without regard to access time. Frequently, a single magnetic core storage unit is updated by the computer and then transferred into separate drum storage units maintained for each individual display channel. For example, this method has been adopted by the Federal Aviation Agency for the Advanced Radar Tracking System at Atlanta.

A color, digital-television display system (DTDS) has been developed for NASA by Philco Corporation. The DTDS produces a 729-line, high-resolution, dot matrix TV format in seven colors. The system allows static backgrounds to be stored digitally and combined with dynamic computer information in an assembly core memory. The backgrounds are stored in a random-access magnetic tape storage unit. The DTDS provides eight independent channels, which are refreshed from magnetostrictive delay-line loops. Each channel stores 746 496 bits in 16 loops. The delay-line storage recirculates one per frame time. The portion of the storage that coincides with the horizontal and vertical blanking periods during sweep return and synchronization is used for special storage of computer words.

Hybrid Systems

At the George C. Marshall Space Flight Center, the Stromberg-Carlson charactron display units provide graphic and textual data to a TV distribution system. The charactron is a shaped-beam cathode-ray tube that is available in a variety of forms. Automatic slide projectors provide background images by direct projection on the tube face from the front. A similar system is in use at the Manned Spacecraft Center in Houston. Other TV cameras monitor digital and analog plotting equipment or teletype equipment at both sites.

Hybrid systems offer the advantage of relatively low cost, but the resolution desired in many applications is difficult to achieve. In digital television, a lower number of TV lines and coarser horizontal resolution permit display of small characters, because the picture elements fall exactly on the lines, whereas in the analog scan, they may fall between the lines or be too narrow for resolution. In a recent experiment at the NASA Electronic Research Center in Cambridge, Mass., a small perturbation to the sweep effectively doubled the number of lines through the visual merger of consecutive slightly displaced rasters. A substantial improvement in vertical resolution was noticeable. This and other bandwidth-conserving techniques are under study in connection with TV monitoring of space activities.

LARGE-SCREEN DISPLAYS

Large-screen display techniques have developed largely from military command and control requirements. The history of the inadequacy of large-screen displays is long and well-documented. In spite of ingenious research, no really successful technique has yet been developed that is suitable for all large-screen display applications. Because detailed parameters based on human factors, the mission task, and equipment availability have often not been clearly defined, large-screen display systems have not been as effective as desired. A discussion of the optimum parameters of a large-screen system and a review of current large-screen display technology may prove to be helpful in this regard.

Large-Screen Display System Parameters

The optimum parameters of a large-screen system can be determined by analysis of the function that the display system is intended to perform. A large-screen display may be desirable when several men are required to view the same information simultaneously, when these men must interact as a group, when these men are required to perform tasks other than observing the display, and when they must view the display from a distance.

The parameters pertinent to a large-screen display system can be described in terms of (1) the human function and (2) the task to be performed. These parameters are discussed in chapter I.

Large-Screen Display Technology

The purpose of this section is to review large-screen display technology in terms of both present capabilities and current developments so that potential users of computer-driven large-screen display systems can relate their needs to realistic existing technology. Standard slide projector, movie machines, and manually operated tote boards are not considered, nor are techniques that hold little promise for the near future such as electrostatic imaging, reflective or transmissive matrices, scribing techniques, and photo-conductive diffraction.

Film Projection—Direct Photography

Direct photography of the face of the cathode-ray tube and subsequent standard optical projection of the image is the most satisfactory technique in use today. Film exposure and development time is about ten seconds. Color is attained by exposing three film patches, each representing a primary color. Projection through a combination of three color filters then completes the color process.

This technique has several distinct advantages: (1) most importantly, it works; (2) brightness is limited only by the optics and light source; (3) if properly aligned, resolution is as good as the CRT image; and (4) because a continuous picture is inherent with a film frame projection system, no flicker problem exists. The fact that a permanent record of each picture is produced is a somewhat dubious advantage. A recall mechanism is needed and an elaborate frame record must be kept if past frames are to be viewed. In addition, the projection equipment is tied up during recall and, once the film spool is replaced, recall becomes impractical.

The disadvantages associated with this technique may make it obsolete for future systems: (1) The 10-second time delay for exposure and processing limits the technique's usefulness to slow-update display applications. (2) The film and chemical processors are expensive because the film frame cost is high (5 to 40 cents each), the film cannot be reused, and the system wastes film. About three frames must be used for leader between each good frame. (3) The complex, electromechanical nature of the equipment requires careful and expensive maintenance. (4) The wet processing imposes undesirable servicing problems brought on by the corrosive nature of the chemicals. (5) The three-color filter overlay technique presents resolution problems. If perfect alignment of the three projection lens system is not maintained, a shadowy effect is produced. (6) Large quantities of film and chemicals must be kept on hand, creating a logistic problem of prohibitive proportions in tactical-mobile applications.

Continuing efforts to improve the direct photography-projection method may extend the life of this large-screen display technology. Several attempts have been made to perfect a dry processing technique, but none has proved successful for high-speed applications. By means of a moving mirror that alternately brings the CRT image and optics into position with the film, a nonmoving film, film-saving technique was developed. Another manufacturer has developed a fairly successful multicolor, reusable film loop in an effort to save film. In the latter instance, the film is cleaned after each use. Advances in film processing methods can be expected to reduce the long processing time to a more acceptable level. Although these improvements may extend the life of the technique, no really significant improvements are expected in reducing installation and maintenance cost, or in reducing update time to a level acceptable for real-time tracking applications.

Photochromic Film

Photochromic materials change color when exposed to one color light and revert to their original state when exposed to another color. For still other colors they may be completely unaffected in either state. Photochromic display

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systems use the properties of photochromic materials to form a photochromic film which serves as a light value. Light from a CRT exposes and darkens the film which is then projected on a screen with visible light in a conventional manner. Another light source or a beam of light can be used for erasure.

One such device consists of a cathode-ray tube with a phosphor that emits ultraviolet light. A piece of photochromic film is exposed to the tube face and the image is transferred directly to the film. To project this image a dichroic mirror is placed between the tube face and the photochromic film. The dichroic mirror passes the ultraviolet but reflects ordinary light. If a source of ordinary light is directed at the film-mirror combination, the reflected image on the film can be passed through a lens system and focused on a large screen. The illumination of the large image is independent of the original cathode-ray tube image. The film can be erased by directing the light from an infrared or heat source onto the film.

The advantages of this technique make it one of the most promising for future practical applications. (1) The film, which costs only about 5 cents per 3-by-4-inch frame, is reusable. Film life of 8 hours has been demonstrated. (2) All of the disadvantages of wet processing are eliminated. (3) The mechanical simplicity of the device reduces maintenance. (4) The essentially molecular process can attain very high resolution. Better than 1000 lines per millimeter is claimed. (5) Because the photochromic material can be applied in a thin layer on the surface of a film or plate or dispersed through a volume of solid material, great flexibility in utilization may be realized. (6) Real-time tracking is possible by writing with multiple light beams on one common surface. (7) By adding an extra infrared light beam, selective erasure becomes possible.

Several disadvantages associated with the photochromic technique keep it from being the solution to all large-screen display problems. (1) Irreversible changes accompany the rapid transition from the clear to the opaque state and back, and thus reduce contrast. The loss of contrast eventually terminates the useful life of the material. (2) Because of losses in the dichroic mirror system, light levels are lower than those possible with direct photographic, wet processing techniques. (3) High-speed symbol writing is not presently possible because of the high amount of energy required to change the state of the photochromic material. Discovery of new materials may alleviate this problem. (4) The negative track (black on white) image formation principle negates the possibility of using additive techniques to produce multicolor pictures. Although subtractive techniques could be used to produce multicolor displays, alignment, contrast, and registration problems arise. If new white-on-black materials could be incorporated into the system, this problem would no longer be an obstacle.

Oil-Film Systems

The distortion produced on an oil-film surface by the action of a scanning electron beam forms the basis for the oil-film projection system. The oil film is spread on a solid conductive surface in an evacuated tube. Electrons striking the oil surface cause an electrostatic deformation at their points of impact: The deformation is proportional to the intensity of the beam. A scanning electron beam leaves a deformed pattern corresponding to the intended image. An external light source passing through or reflected from the oil film is refracted by the deformed areas. The amount of light refracted is proportional to the depth of the deformation. Light striking undistorted areas of the screen is reflected back to the light source. An optical lens system then forms and enlarges the white-on-black image and directs it to the screen. An oil-film projection device (Eidophor) distributed by Theatre Network Television, Inc., is being used now in both commercial and government applications.

When properly tuned, oil-film large-screen display devices demonstrate several impressive characteristics. (1) Resolution of 1000 television lines or better is achievable. (2) A newly developed color technique that involves the differences in diffraction of the various wavelengths of light as they are reflected from the oil film has eliminated earlier color-smearing problems. (3) The brightness of the display is satisfactory for most uses. (4) The system can dynamically display true real-time moving targets.

The greatest problem with oil-film projection systems is caused by contamination of the cathode by the oil. This contamination seriously limits cathode life. Adding turret-mounted cathodes only partially resolves the problem. The limited cathode life discourages the use of this type of equipment in many military applications where reliability factors are critical.

Deformable Plastic Tapes

The principle of operation of the deformable thermoplastic technique is similar to that of the oil film method except that the surface charged by the electron beam is heated to form the deformed areas. Light passed through the deformed tape projects the image onto a screen. To react to the electron beam the tape must be used in the vacuum of the electron tube. Another approach that places photoplastic tape on the outside of the tube but deforms the tape with an intensity modulated light beam may resolve this problem. Because of the diffraction nature of the thermoplastic and photoplastic materials, special optics, such as schlieren optics, are necessary for readout. The resolution of present thermoplastic systems is limited to 40 lines per millimeter. The comparatively short processing time of this technique is the main attraction.

Discrete Elements Display

A number of techniques exist to provide large-area arrays of discrete elements. Discrete arrays have been in use for many years in advertising displays. Many of those in Times Square in New York City and similar areas are based on discrete arrays of lights. Two developments that are becoming increasingly important are electroluminescent and plasma discharge cells.

There are two principal types of electroluminescence: field-effect electroluminescence and carrier injection electroluminescence. Field-effect electroluminescence is the excitation of a phosphor by a varying electrostatic field. A familiar application of the effect is in night lights for hallways and children's rooms. Carrier injection electroluminescence arises from the recombination of positive and negative charges in semiconductors. It is a steady-state phenomenon and devices using it are compatible with solid-state and microelectronic components.

Plasma discharge cells fall into two categories: those containing internal electrodes and those having external electrodes. The internal electrode plasma discharge cell directly conducts electricity. The external electrode plasma discharge cells require a varying electrical field for excitation and operate through capacitive coupling.

The phosphors used in field-effect electroluminescence are similar to those described previously for cathode-ray tubes. The same research programs usually test each new phosphor for many excitation modes, including electroluminescence in which light is emitted when the phosphor is exposed to a changing electric field. The light intensity depends upon the frequency and amplitude of the change. Two-dimensional arrays are activated by selection of intersecting row and column conductors so that the element between receives a larger excitation than its neighbors.

As described, the array must be repetitively scanned, because there is no storage in the element. Photoconductive elements can be combined into the array that use light from the element to maintain current through it. These units are less reliable than purely electroluminescent elements and have catastrophic failure modes. Also, the arrays are sensitive to room lighting unless special multiple element structures are employed. The photoconductive-element/electroluminescent-element combination has been used as a light amplifier and it may be used in future large-screen projection systems to intensify weak projected images.

When limited to a single dimension, electroluminescence has been applied to aircraft instruments of the vertical bar indicator type. An instrument of this type developed for the Ames Research Center of NASA by Aerospace Products Research Corp. is shown in figure 5. For instrument applications electroluminescence offers the advantage of being solid state with no

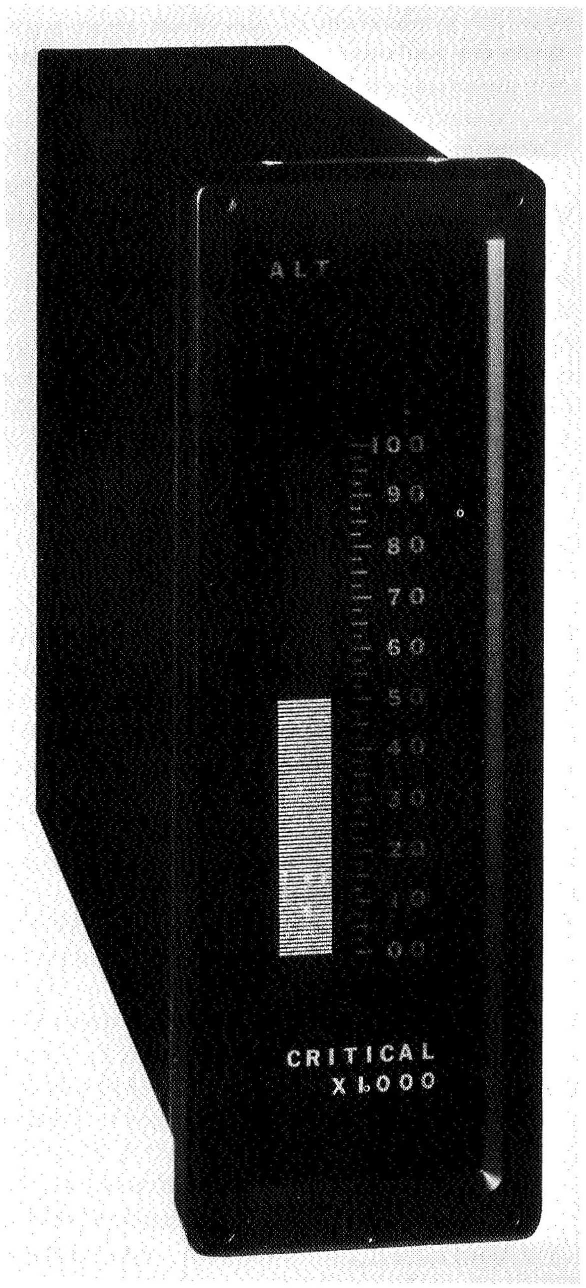

FIGURE 5.—Electroluminescent altimeter scale. Electroluminescent elements in a one-dimensional array provide a linear readout in this altimeter. Electroluminescence also provides selective control of alphanumeric information on the instrument face.

moving parts. In all applications the failure mode of electroluminescent elements is gradual with end of life being marked by deterioration below a specified level rather than a sudden extinction.

Carrier injection electroluminescence is exhibited by light-emitting diodes and other semiconductor elements. At present these devices have been used primarily in small arrays for the production of single characters. One application has been the generation by dot matrix of serial numbers to identify photographic records. Other applications use the good frequency response characteristics in combination with photosensitive elements to perform special logical or electronic functions.

Electroluminescent lamps are not limited in shape and form. No projection equipment, and therefore, no throw distance is required. The size of the display is limited by the physical problem of exciting, switching, and controlling large numbers of discrete illuminated points.

When used for large displays, a large number of discrete elements must be individually controlled. Segmented elements can be fabricated as point light sources or as shaped light forms. Individually segmented elements can be arranged in a fixed format and can display rigid alphanumeric information. Arranged in bar form, the segments can indicate air or ground traffic flow, communication link status, or industrial process flow.

A crossed grid approach can be taken to provide a more flexible display unit, and therefore a system more applicable to a variety of applications. In this method, an electroluminescent layer is placed between two sets of electrodes. Each set contains a number of parallel conductors. The two sets of electrodes are orthogonal. By applying a voltage to a pair of x and y conductors, a small spot of light can be produced at a predetermined point. Current technology permits about 50 lines per inch or about 2500 elements per square inch. About 100 lines per inch is considered feasible.

At first glance, electroluminescent techniques appear to be the simple solution to many of the problems encountered with large-screen projection systems. Many difficulties in the basic system, however, must be solved before this technique will find general application to large-screen displays. Problems with brightness, contrast, switching complexity, memory, voltage requirements, and multicolor limit the usefulness of this approach. (1) Brightness in large-screen applications suffers because of the difficulty in supplying sufficient excitation voltages to a large number of discrete points at the rate needed to prevent display flicker. In an 8-by-8-foot display, with 50 lines per inch, or 2500 points per square inch, approximately 23 million light points would need to be excited 30 times each second. (Thirty frames per second is considered a standard rate for flicker-free displays.) The scanning becomes so rapid that discrete-point pulse duration is not long enough to energize each spot to adequate brightness. (2) Contrast becomes poorer as point or line density increases. Overlap of electrical field caused by the basic electroluminescent capacitive effect and the cross-grid geometry further decreases the contrast. If enough points are plotted, it becomes impossible to distinguish between selected areas and background areas. (3) Switching complexity grows with screen size. A switching and line driver circuit is required for each X–Y grid line. Even if a block approach is used, the total number of components needed to display complex, high-resolution information exceeds practical price and reliability limits. (4) The basic system has no memory capacity. Therefore, data must be supplied at a sufficiently high rate to prevent flicker or a memory element must be built in. If the direct refresh method is chosen, expensive external storage is required. To build in memory, a number of techniques have been tried. Photoconductive elements placed behind each resolution element induce a light-reactive feedback voltage to keep the desired spot excited. Light striking the photoconductive cell reduces its resistance and thereby permits an external voltage source to reach the desired electroluminescent element. In addition to overcoming the memory problem, the photoconductive cell also improves brightness and contrast. By adding another component, however, the system reliability falters, resolution lowers, and cost increases. Because photoconductive cells do not switch resistance instantly, the maximum rate at which information can be displayed is also limited. (5) Another problem with the cross-grid approach is the high-voltage requirement. The use of transistors is limited because required voltage levels often exceed the 100- to 150-volt transistor range. (6) The final problem involves color. Depending upon the phosphor selected, a variety of colors for an individual element can be chosen initially.

A recent development for the Electronic Research Center of NASA by Huyck Systems Company has been a new class of high-contrast display elements. The element uses internal reflection combined with fluorescent regions in a light pipe to produce a full-color display. High contrast is achieved since light entering from the front passes through the fluorescent regions and is lost. The fluorescent dyes are excited from the side by electroluminescent elements. Brightness and number color depend on the depth of the element.*

Plasma discharge cell arrays may be constructed with either internal or external electrodes. Those with internal electrodes resemble arrays of neon bulbs. They can be selected on a row-column basis and each cell has storage capability so that scanning for regeneration is not required. Individual cells must be isolated electrically by resistors or other means and each cell requires space-consuming sealed electrodes. For these reasons and because of gradual darkening caused by electrode bombardment, large arrays of internal electrode plasma cells have so far been exhibited only in experimental models.

A promising plasma discharge cell technique motivated by the needs of the PLATO program discussed in chapter V has been developed by the Coordinated Science Laboratory of the University of Illinois. This development employs external electrodes in a crossed grid configuration. Between each intersecting pair of transparent electrodes is a small, sealed, gas-filled cell etched into a thin glass plate. Cells are selected by applying a pulse to the appropriate X and Y electrodes. In addition, an alternating voltage, sufficient initially to sustain conduction and initiated by the selected pairs, is applied between the set of X and the set of Y electrodes.

When the cell is in a non-conducting state the sustaining voltage has no effect. If a selected pair of electrodes is activated so as to add to

* See Electronic Design, Feb. 1, 1967.

the sustaining voltage, the cell breaks down and conducts. During conduction, electric charge is deposited on the opposite cell walls and causes the impressed voltage on the gas to be reduced until extinction occurs; that is, the cell becomes polarized. During the next half cycle the sustaining voltage is in the opposite direction, adding to the polarization voltage across the cell, which now breaks down in the opposite direction. After a few cycles the cell comes to equilibrium and remains in a conducting state thereafter. The cells may be extinguished individually or the entire display may be erased as desired by various means.

Linear cell densities of 40 cells per inch have been achieved, and densities of 100 per inch appear to be possible. It is still necessary to provide separate X and Y decoders and considerable work remains to be done, but the plasma display panel offers great promise of providing a useful alternate to the cathode-ray tube. This promise will be particularly appreciated in remote applications in which access to cheap bulk storage may not be possible.

MAN-MACHINE REACTIVE INPUT DEVICES

Communication between man and machine in a real-time environment is becoming more important as the complexity and capabilities of computing systems increase and our needs for automation grow. To solve problems of interest to human beings, efforts should focus on systems in which man and machine can cooperatively make up for each other's deficiencies in problem-solving capacity and at the same time maximize the advantage peculiar to each. The human sensory, intellectual, and motor faculties permit reaction to a wide range of dissociated stimulus. Man's ability to analyze large quantities of data rapidly, however, is often severely limited. It is this area that computers can serve to the best advantage. In attempting to combine the best of both man and computer, the problem has been to take advantage of man's unique ability to interpret information subjectively and at the same time to present the same data to a computer in a digitally simplified form that the computer can digest.

A number of devices can be used as the media for entering data into a computer. These include punched cards, paper and magnetic tape, and several reactive type input devices such as keyboards, request panels, function switches, light pens, joysticks, and tracking balls. Here the real-time reactive input device is of most interest. (See table III for a brief list of application areas versus applicable input devices.)

Before a potential user of a display system selects a display control and data input tool, he should consider the primary function for which the device is intended. Having defined the primary function, one can proceed to determine the characteristics most desired in an input tool, what display control devices are available, what are the characteristic advantages and limitations of each, and what combination of devices will be most useful in the given application.

Reactive data-input, data-control devices are used for several distinct purposes:

(1) Input of variable length textual information.

(2) Input of manually traced, pictorial information.

(3) Input of preformatted fill-in-the-blank messages.

(4) Selection of expanded data on items of particular interest.

(5) Creation of free-hand sketches of pictorially represented information.

(6) Conveyance of formulas for problem solution to a computer in computer-problem-oriented or machine-oriented language form.

(7) Selection of an item from an array of functional choices.

(8) Selection of stored data base information.

No one reactive input device has characteristics broad enough to accommodate successfully this range of applications. Reactive input devices, however, should have the following basic characteristics:

(1) They should be designed so that an operator can easily learn to use them and they should relate readily to the most common of all design tools, the pencil and paper.

(2) They should not require an elaborately controlled physical environment or a complex installation interface.

TABLE III.—*Applications and Input Devices*

Application	Fixed positioning		Random positioning								
	Keyboard	Function switch	Light pen	Beam pen	Rand tablet	Pressure sensitive	Voltage pencil	Lincoln wand	Joy stick	Tracking ball	Mouse
Communications											
Reservation systems	modified X	X									
Teletype	X	X									
Critical Message Validating	X	X	X	X	X	X	X				X
On-line text editing	X	X			X	X	X		X	X	X
Event Monitoring											
Military-command control		X	X	X	X	X	X	X	X	X	X
Equipment checkout		X	X	X	X	X	X	X	X	X	X
Assembly line monitoring		X	X	X	X	X	X	X	X	X	X
Creative design											
Flow charting		X	X	X	X	X					
Mechanical drawing		X	X	X	X	X					
Animation		X	X	X	X	X					
Hard-copying		X			X	X					X
Scientific research calculation		X			X	X					
Management information											
File searching		X	X	X	X	X	X	X	X	X	X
Accounting	X	X	X	X	X	X	X	X			X
Education	X	X				X					X

(3) They should require minimum programming support.

(4) They should be cost effective. This statement may border on the trivial, but hardware and software interface costs, when added to the price of the input device itself, may exceed justifiable limits.

Reactive computer/display input devices fall into five general categories: keyboard, function switch, beam sensitive, *X–Y* grid coordinate, and potentiometer. Considerable progress has been made recently in perfecting reactive input devices. The most significant are described below.

Keyboard

The standard typewriter with computer interface modifications is the most common on-line, computer-input, display-control device. Wherever a requirement exists for rapid textual information input, the keyboard can be a valuable aid. Because the usefulness and limitations of the keyboard are commonly known, its detailed design, applications, advantages, and disadvantages will not be discussed here.

Function Switch

Function switches are normally used to supplement pointer and data entering input devices. When an operator depresses one or several of these switches, a specific action request is sent to the interfacing computer or display processor. For example, in a text editing system an operator could indicate a space with a pointing device, type a word on a keyboard, and depress a function switch labeled INSERT. If the function switch is controlled by a computer program, the meaning of the switch can be made different for each program being run.

The biggest problem with function switches arises when the operator must select the appropriate buttons from a large number of combinations. The problem can be largely overcome in several ways. One may color code the switches and arrange them according to related tasks. When several switches need to be selected, the first can light up a restricted number of buttons that limit subsequent choices. Finally, a prudent selection of self-explanatory labels results in less confusion when the meaning of the switch is changed.

Beam Sensitive Type

Light Pen

One of the most familiar devices for on-line graphic input is the light pen. One design consists of a fiber-optic bundle that terminates in a photomultiplier tube. Light from the face of a CRT display enters the pen through a simple shutter that opens when a button on the pen is depressed. When light comes within the field of view of the light pen, pulses are generated by the photomultiplier. The position of the pen on the tube face may be determined in several ways. In one approach, a special symbol, usually an open cross, is positioned on the screen, then acquired by the light pen. As the pen is moved to the desired position, the cross follows it via an optical servo system. The direction of travel is sensed by determining which of the four cross arms was last seen by the pen. In another approach, the position of the pen is determined by synchronizing the position of a high-speed, continuously scanning CRT beam with impulses generated when the light pen senses light. Depending upon the option desired, the light pen, in combination with function switches, can be used to draw lines, select a specified information point, or track a moving target. The pen can be employed to simulate function keys or simulate an alphanumeric keyboard.

The principal disadvantage of the light pen is that complex tracking algorithms are required to determine pen position, particularly when the pen is used for sketching because the programming (or hardware) interface becomes complicated. In addition, the comparatively wide field of view of the light pen limits its accuracy. Overshooting or undershooting a moving target while tracking is common. Speed of response is often said to be the primary advantage of the light pen, but some of the newly developed *X–Y* coordinate and potentiometer types are just as fast. Provided a light pen is used only to indicate an item from a displayed array, in which programming or hardware interface is simple, the light pen input system is competitively priced with other input systems.

Beam Pen

The beam pen detects the presence of traces on the cathode-ray tube by capacitive pickup and may be applied in much the same way as the light pen. Design work began on the beam pen as an approach to overcoming the comparatively low-light reactive speed of the light pen. To display complicated flicker-free pictures with modern computer display systems, it is normal to display points about every 2 microseconds, but it was found that it was difficult to distinguish among points displayed so closely in time even given the fastest available photomultiplier tube (light pen). Beam pens now under development can respond to significantly higher display rates. The beam pen is competitive in simplicity of design and cost to light pens and is insensitive to ambient light. The poor resolution of the beam pen does not appear to be an insurmountable engineering obstacle, but its current 1.5-inch diameter field of view prohibits application where detailed images are important.

X–Y Grid Coordinate Type

Rand Tablet

The Rand Tablet, a graphic input device that has recently become commercially available, consists of an X–Y plane of conductors just below the surface of a writing area and a capacitive sensing stylus containing a high-gain amplifier. Each X–Y line is fed an identifying 10–bit serial pulse train. When the stylus is positioned on the writing surface, it interrogates the closest X–Y pulse train thereby determining its position. Because the stylus need not touch the writing surface to operate, hard-copy tracing is possible. The Rand Tablet enjoys fast response and offers high accuracy. It is easily interfaced to a computer and the basic operating software is not complicated. If the tablet is combined with any one of several standard computer display units, the costs for display generation and refresh hardware and/or software requirements increase. A primary limitation of the Rand Tablet is its high cost, which is contributed to by its intricately complex manufacturing specifications. Another limitation is the small size of the tablet. The size prevents a draftsman from using the tablet to work with large drawings or blueprints.

Pressure-Sensitive Encoder

Because of the incompatibility of the light pen with hard-copy work, a number of other devices have been developed. One of the more promising is the pressure-sensitive encoder. In this device two sets of parallel conductors are arranged orthogonally. One set is recessed in a glass epoxy substrate while the other set adheres to a sheet of mylar film. The pressure of an ordinary writing tool, such as a pencil, establishes electrical contact between the two X–Y conductors. Present pressure-sensitive encoders have a small 2- by 5-inch working area and have relatively low resolution of 32 lines per inch. No engineering design or manufacturing difficulties, however, prevent larger and higher resolution units from being built. The output of the pressure-sensitive encoder is digital so that direct computer interface is simplified and software position calculations are minimized. Like most other non-CRT-beam-sensing devices, this unit may operate independently of display equipment.

Voltage Pencil (Light Pencil)

The voltage pencil resulted from efforts to overcome positioning and tracking difficulties associated with the light pen. The desired display location is specified by touching a conducting probe to an electrical grid that is placed over the face of the cathode-ray tube. The grid is made transparent to pass emitted light. Voltages are applied to the outside ends of the grid conductors so that the probe picks up analog voltages proportional to the horizontal and vertical coordinates of the point being touched. The voltage pencil has lower resolution than the light pen and is more difficult to manufacture.

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Lincoln Wand

The Lincoln Wand is presently being tested for inputting display data by referencing a three-dimensional coordinate system. Four ultrasonic transducers positioned around the periphery of a display area sequentially transmit pulses that are detected by a sensitive microphone in a hand-held wand. A digital counter is started at the beginning of each transducer pulse and stopped when the signal is detected by the wand microphone. The counter values are transmitted to a computer that calculates XYZ display coordinates. The direct digital readout has the advantage of eliminating the need for analog-to-digital conversion and simplifies software-display coordinate calculations. The prototype instrument is reported to be a valuable tool for sketching in three dimensions and for selecting data from an array. The large working space ($4 \times 4 \times 6$ feet) and the use of the Z-axis control as a number value adjuster, permit quick access to large amounts of library data without "tree searching" or loading the edge of the display scope as is the case in two-dimensional devices. The greatest drawback of the Lincoln Wand is that anything placed within the working space scatters the ultrasonic pulses traveling between the transducers and the wand.

Potentiometer Type

Joystick

The joystick is a lever device which can be used to generate vectors, add alphanumerics, or point to an item in an array. It may operate in either of two modes, slew or proportional. In the slew mode, a display-screen trace moves at a constant speed in any direction indicated by the lever. The trace is stopped by releasing the lever. In the proportional mode, the trace moves at a distance proportional to the amount that the joystick is moved. Function switches and an activate switch, used in conjunction with the joystick, permit the operator to select or delete symbols, move them about the display, or position them as desired. A special cursor, such as a cross, shows the operator where he is. The similarity of a joystick to other air- and spacecraft controls makes it particularly useful in aerospace vehicle-maneuvering displays and with aerospacecraft simulator-display units. The positioning accuracy of a joystick is generally superior to that of a light pen and it operates quickly. The device is not adaptable to hard-copy operation and is not particularly useful in sketching applications.

Tracking Ball

The tracking ball is a hand-controlled device that can be used to move a cursor by rolling a mounted ball in any direction. Like the joystick, the tracking ball takes advantage of potentiometers to develop analog voltages representing desired display-screen coordinates and is restricted to cursor-positioning applications. The tracking ball is a sturdy, low-cost means for pointing to display items for an array, but is not readily adaptable for hard-copy or sketching applications.

SRI Mouse

The SRI mouse is an ingeniously simple device developed at Stanford Research Institute by Douglas C. Englebart as a display input and control tool for investigating interactions between man and machine. The mouse consists of a simple pair of orthogonal drive wheels connected to rotary potentiometers. When the mouse is moved the wheels turn and generate an analog signal proportional to the vertical and horizontal motion of the device. Three top-mounted small buttons act as activation and function switches. The mouse is being used for text editing, file searching, and graph structuring applications. With little additional effort, the mouse could be adapted for sketching and tracing operations. Two of the attributes of the mouse are its low-cost design and the fact that it may be used in any position on nearly any surface.

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CHAPTER III

Computer Systems

Since we are concerned primarily with computer-driven display systems, the reader needs some idea of the types of computer systems which can be involved, including both the hardware and the software. Computer systems consist of at least one computer, a set of input/output devices, and a library of programs; they are established as general-service systems or special-purpose systems, and vary in complexity from single-computer, single-function systems to multicomputer, multifunction systems.

This chapter discusses the primary characteristics and some of the complex and advanced features of computer systems. Multiprocessing systems and special systems are included, e.g., advanced programming facilities often attendant with large systems, and user languages developed to enable easy use of computer systems. Finally, special software developed for display systems is discussed.

SYSTEM CLASSIFICATION

The organization of a computer system is heavily influenced by the intended use of the system. General-purpose, multiprocessing systems provide sufficient flexibility to accommodate applications ranging from business to scientific.

The important factors of special-purpose systems are generally rapid receipt and processing of input data, rapid reporting of results, and non-vulnerability of the system to single failures within the system.

Multiprocessing Systems

Multiprocessing systems are basically general-purpose systems that can accommodate a large number of users with a variety of problems. These systems are usually best suited to serve applications such as business data processing but can be used with a reasonable degree of satisfaction for other work. Three primary types of multiprocessing systems have been developed: batch-processing systems, time-shared systems, and multicomputer systems.

Batch-Processing Systems

Batch-processing systems are the multiprocessing systems with which most people are familiar. There is generally a central processing unit connected to a set of input/output devices and an operations staff. When a user desires a computing service available in the system, he submits a run request together with his data. The operations staff performs scheduling and file directory services such that each run is performed in its turn and users may retain files for future use without having to take physical possession of the file-storage medium. The runs vary widely with respect to the type of processing performed, and the time required for the solutions may vary from a few minutes to a few hours. The computer system is generally dedicated to the current job in progress.

Time-Shared Systems

Time-shared systems provide computer services to system users simultaneously on a real-time basis. These systems differ from batch processing systems in three significant ways. First, each user is given access to a terminal device that constitutes the user's primary interface with the system. Through this device, the user requests access to the system, supplies inputs, and receives outputs. Second, an executive system performs the scheduling and some bookkeeping functions normally handled by operations personnel in a batch-processing system. These functions include the allocation of computer time and system resources among active users, the maintenance of a file directory, and the accounting of system usage by user for billing purposes. Third, because many users are actively sharing the computer system, there must be an operating system that maintains order within the central processor.

Multicomputer Systems

A multicomputer system is a system containing two or more computers that can communicate directly with each other. Many such systems are special purpose (discussed below). In many others, one computer forms the heart of the system with the remaining computers providing interfaces with input/output devices. In the latter case, the system can generally be considered as a single computer system.

A third type of multicomputer system consists of numerous computers and a set of input/output devices, with no particular organization. Within certain constraints, any input/output device may be connected to any input/output channel of any computer. Any computer may be allowed to communicate with any other and the computers may be of many different types. In such a system, one of the computers is generally assigned the system-executive function. This computer is responsible for allocation of system resources among users and for establishing the connections between the computers and the input/output devices necessary to form the hardware configurations required by each run.

A large multicomputer system must be justified by significant user requirements for computational services. The primary advantages of such a system are flexibility, economy, and reliability. The failure of a device in the system does not obviate the use of the remainder of the system as is often the case in other types of systems. Thus, the system can ensure full-time operation with lower excess capacity than can any other type of system. Further, a lesser number of input/output devices usually is required than would be required by the same number of computers in single computer, fixed-configuration systems.

Special-Purpose Systems

Special-purpose systems are developed to satisfy specific needs and generally fall into one of two categories: specialized or dedicated. Specialized systems are systems that have been constructed for and adapted to a particular application. Such systems are not generally useful in any other application. Dedicated systems are basically general-purpose but supply a particular service on a full-time basis. Communication systems, for example, are dedicated systems.

PROGRAMMED SUPPORT SYSTEMS

The need for programmed support systems varies greatly from system to system depending primarily upon the basic purpose of the system, the diversity of problems to be handled, and whether the system is to be used in a batch-processing or time-shared environment. There are operating system programs and executive system programs for the more advanced program systems that increase the effectiveness and economies of the computing system. Time-sharing systems have been developed to provide computing capability to users who have frequent but small demands.

Operating Systems

Operating system programs provide support to applications programs, while system executive programs provide support to operations personnel. The primary objective of an operating system is to reduce the effort required in the design and implementation of applications programs and/or to standardize common operations by supplying universally required functional services.

Input/output device manipulation and control is the primary service provided by an operating system. This service requires the application program to provide the starting and ending addresses of a buffer area, the operation (read or write) desired, and the device of interest. The appropriate operating system function then determines when the stated device is available for use, performs the requested operation, checks for errors to determine that the operation is successfully completed, performs error correction operations such as roll backs in the case of errors and then informs the applications program that the requested operation is complete or, in the event of a non-correctable error, that the requested operation is non-performable without more drastic corrective measures than are available to the operating system.

Other operating systems can cope with more complicated measures. For example, an applications program may specify a logical device. The operating system (or the system executive) then selects the actual physical device for a specific run. Further, the operating system may be able even to substitute one type of physical device for another. If a printer is not available, the operating system may select magnetic tape for output.

System Executive

System executive programs (sometimes referred to as system supervisor programs) are developed to provide support in the supervisory management and control of a computer system. These programs provide services to operations personnel by performing bookkeeping and scheduling functions that would otherwise be handled by people. Generally, the more complex a computer system is, the greater the need is for a system executive. A system executive is an absolute necessity in any computer system that is to provide a time-shared service.

In the simplest application, a system executive may record the running time of each run and provide services such as clearing memory between runs. As computer systems become more complex the services of the system executive may be expanded. Generally, added services consist of scheduling work, assigning tasks and scheduling computers and input/output devices in a multicomputer installation, maintaining file directory, and allocating space on fixed storage devices such as drums and discs.

If an operating system provides for logical reference to input/output devices and/or substitution of device types, then the system executive usually designates the specific device to be used. Further, if substitution is made, such as the substitution of magnetic tape for printer, the system executive will usually generate a request for a special corrective run, such as a tape-to-printer task that will not be run until the printer becomes available. Thus, the user ultimately receives the desired result, such as printed output, without being required to request an additional run.

Time Sharing

A time-sharing system is any system that includes an operating system program and an executive system program, the combined features of which ensure complete system control while allowing simultaneous general usage of the system by two or more persons.

Access to a time-shared system is acquired by a user at a terminal. The user performs a connection procedure that may include terminal and user identification. The procedure establishes a connection to the time-shared system and also establishes the validity of the terminal and user as authorized subscribers. Having established access to the computer system, the user is then able to utilize system supplied programs such as compilers and file maintenance routines. He also has access to programs and data files that he has generated during previous runs and has directed the system to save. Time is considered in fixed increments and allocated one increment at a time to each of the active users in turn by the system executive.

USER LANGUAGES

User languages have been developed to enable personnel skilled in a field other than computer programming to utilize computer systems effectively. The primary objective is to provide a mechanism by which these users can obtain computer services and processing in support of some larger task without having to suffer the expense and lengthy delay of defining a specific task and acquiring the assistance of a skilled programmer for its implementation. The requirements of different users often vary only slightly, and, the expense of producing a program for each separate user may be significant and duplicatory. User languages fall into two basic categories: information retrieval and query languages, and data processing languages. These are discussed in detail below.

Information Retrieval and Query Languages

Information retrieval and query languages have been developed primarily for the establishment, maintenance, and rapid access to files of data. Systems using these languages have been developed for command and control systems, and business management systems. Generally, in these systems, the primary user requires rapid access to information contained in files that he does not maintain. Moreover, the information generally is rapidly changing, and its timely availability is significant to the user.

Data-Processing Languages

Data-processing languages are currently less prevalent than information retrieval and query languages. The primary purpose of data-processing languages is to manipulate data effectively as opposed to rapid access to prestored data.

Editor systems, one of the most common kinds of data processing systems, are based on a user language. These systems permit the establishment of a data file and subsequent recall of portions of it for editing. While these systems are most effective for the manipulation of textual material, there is no inherent reason why an editor system should be limited to text alone.

Mathematical languages have also been developed that enable engineers to use computers without programming experience. An engineer can state a complex formula or sequence of formulae in these languages and then, by inputting a set of variables, receive an immediate calculation based upon the given variables.

SPECIAL DISPLAY EQUIPMENT ORIENTED SOFTWARE

Display equipment incorporated into a computer system provides input/output capability that often requires special handling. The primary considerations relevant to displays necessitating special attention are: timing, character codes, and optical characteristic options.

Outputting of data to a printer or other data storage device requires the preparation of data in a predetermined format and then writing the data to the device, where it is retained in a stable condition. Timing considerations reduce to not using the device until it has completed the previous operation. This problem is generally handled by the program designer who attempts to minimize waiting time. Characters are represented by discrete codes and there are few options available relevant to the physical characteristics of the data presented.

In display devices a significant problem arises with regard to timing because fading and flicker will develop if a minimum refreshment rate is not maintained. The program designer can alleviate timing problems to some extent through general organization of the information to be displayed and through the use of large increment values where possible. This solution is, however, only partially effective and in cases where timing may be a serious problem, special software must be developed that analyzes the information to be displayed and calculates the display sequence requiring the minimum time to produce.

The characters on many types of display devices are presented as a set of straight line segments oriented to each other so as to give the desired visual effect. Thus, the code for a particular character is a sequence of instructions that guide the movement of a beam. These instructions are generally too cumbersome and inefficient to use as an internal data processing code. Furthermore, the display code for a particular character may require 10 to 15 times the quantity of memory required by the normal data processing code for the character. Therefore, even a code conversion of character information to be displayed may involve excessively large quantities of memory. One solution to this problem is the character generator. These devices provide subroutines for the generation of each character when presented with the normal data processing code of that character. Hardware character generators, however, have been developed to overcome software problems.

Many display devices provide a set of brightness (intensity) levels and/or scales (beam step sizes) from which the software may select a particular value. Additionally, special features, such as blinking, may be provided. All of these features are switchable so that once a selection is made, variation occurs only if and when a different selection is made. Changes may be selected at any control step; thus, individual items or areas of a display may vary in intensity or scale from that of the general display. While these options are unique to display devices, they generally do not present a problem nor do they require significant software.

The inputs associated with display equipment are obtained through special input devices, the characteristics and operation of which already have been discussed. Software support to these devices is required primarily in the areas of character recognition and the interpretation of function selection switches.

The acceptance by a computer system of handwritten character input is primarily the problem of character recognition. The hardware capability for detecting continuous strokes exists in a number of display related devices. The ability to recognize certain strokes and/or combinations of strokes as representing discrete characters is generally provided by software. Much work has been and is being done in the character recognition field. Current capabilities in this area are restricted to recognition of stylized printed characters with some allowable deviation from the required style. These allowable deviations are generally quite small, thus requiring much care on the part of the user in order that each character be properly recognized. In an on-line system, this restriction is not serious because each character is recognized as it is written and the writer can immediately correct a machine error.

The use, operation, and software support of function selection switches is not unlike that of function switches associated with normal computer consoles. The activation of a function switch causes an input to which the software must respond and determine the function indicated. There are, however, some special input devices associated with displays, such as a light pen or sensor, that may provide a function-selection-type input. This input requires a two-step process to determine its significance. The input device produces a signal that indicates there is an input available consisting of the coordinates of an item being displayed. The software then responds to the signal, reads the coordinates and then uses the coordinates to identify and retrieve the designated item. The input thus obtained may be self contained such as a canned query or may simply identify a symbol or location on which an operation is to be performed. In the latter case, the operations, such as intensify, blink, remove, etc., are normally designated by use of a function selection switch.

MANAGING THE SOFTWARE PROBLEM

Computer programs are an integral part of reactive display systems that require the input and processing of data base information. Software may account for 50 percent of total display system development costs. A display system development manager must possess a strong understanding of the scope of the software task. He must be aware of all those factors that vary program production costs and he must have a plan for directing and controlling his resources. He must know what the programming functions are, what tasks must be performed, and what resources are required. Principles of management are well documented. Those factors, however, that affect software development costs and vary software production schedules are not as clearly defined.

Cost Varying Factors

The first and often most difficult task in producing a workable computer program is defining the problem. If the problem is not clearly stated in the beginning, the tasks of analyzing and designing the software system becomes much more difficult. Much programming effort may be wasted solving the wrong problem.

Program costs vary greatly. If the system functions call for unique and untried or large, complex programs, both the prediction of resource requirements and the design and production of programs become difficult.

The experience of managers, system designers, program designers, programmers and system test personnel has a direct bearing on both man-month expenditures and dollar costs. Because computer display hardware and visual display applications are being developed faster than software system managers and technical people are being trained, finding experience is becoming a problem of considerable proportions. Little has been done to record, systematize, or generalize programming production experiences. New programming techniques, such as data management systems, query languages, and programming languages, have developed faster than managers can be trained.

The availability and reliability of computer facilities, including the computer and all its associated peripheral devices, and the dependability of supporting software can greatly affect program production expenditures. Unreliable hardware becomes particularly costly when programmers must travel to the computing installation. An inoperative card reader can idle the best programmer. An assembler or compiler that is highly sensitive to tape unit problems, or does not function exactly as the reference manual directs, will frustrate any manager's plan. Poor computer usage scheduling can also wreck the best-laid production schedule. Because progress in the coding and testing phases of the software task depends on the availability of system hardware, close attention should also be paid to the effect of hardware delivery on program production.

The organizational control and the function of service groups must be clearly defined. Both the quality and the scheduled use of such service group functions as keypunching and printing will affect both software development costs and production schedules.

Personnel Requirements

Before a software system manager can begin to predict the extent of the software effort, he must know what types of people are required, what the basic machine requirements are, and the scope of the software task. He should know the functions of the technical production people and the programming phases with which they are associated (figs. 6 and 7).

The display problem must first be defined by problem-oriented engineers. These people state exactly what problem is to be solved. Once the problem has been clearly stated, system design engineers can analyze total system requirements in terms of the stated problem. They can pinpoint the role of software and can lay down a framework for the structure of the total system, both software and hardware. They can analyze all the factors that affect software production and can determine what effect variations in these factors will have on system development and effectiveness. Together with the operational users of the display system, the system designers define input and output data and format requirements.

Mathematical analysts may be required to support both system designers and program production personnel. The mathematical analysts may be needed to provide statistical analysis support for system effectiveness studies. They may be required to do much of the work in designing and writing math models and simulators or in writing operational program mathematical calculation routines.

Senior program designers are needed to translate system design functional requirements into the computer environment. They partition logically the functional tasks of the program, specify the logical design of the program, and allocate computer memory, drum, disc, magnetic tape, or other available computer storage for each program task.

Senior and junior programmers are needed to write the detailed flowcharts for task, code the programs, and debug the routines. They are required to coordinate changes in program design with senior program design personnel. They have to support system test personnel by providing assistance in writing test plans.

Particularly in the case of large systems, personnel are required for system test, integration, and acceptance. They are responsible for writing system test plans and directing system tests.

A documentation controller can provide valuable assistance to the project manager by coordinating, scheduling, and monitoring all documentation. When program production schedules begin to slip, documentation output is the first to suffer. It is important that program documentation be complete and accurate. Training new people can be greatly speeded up if good documentation is available.

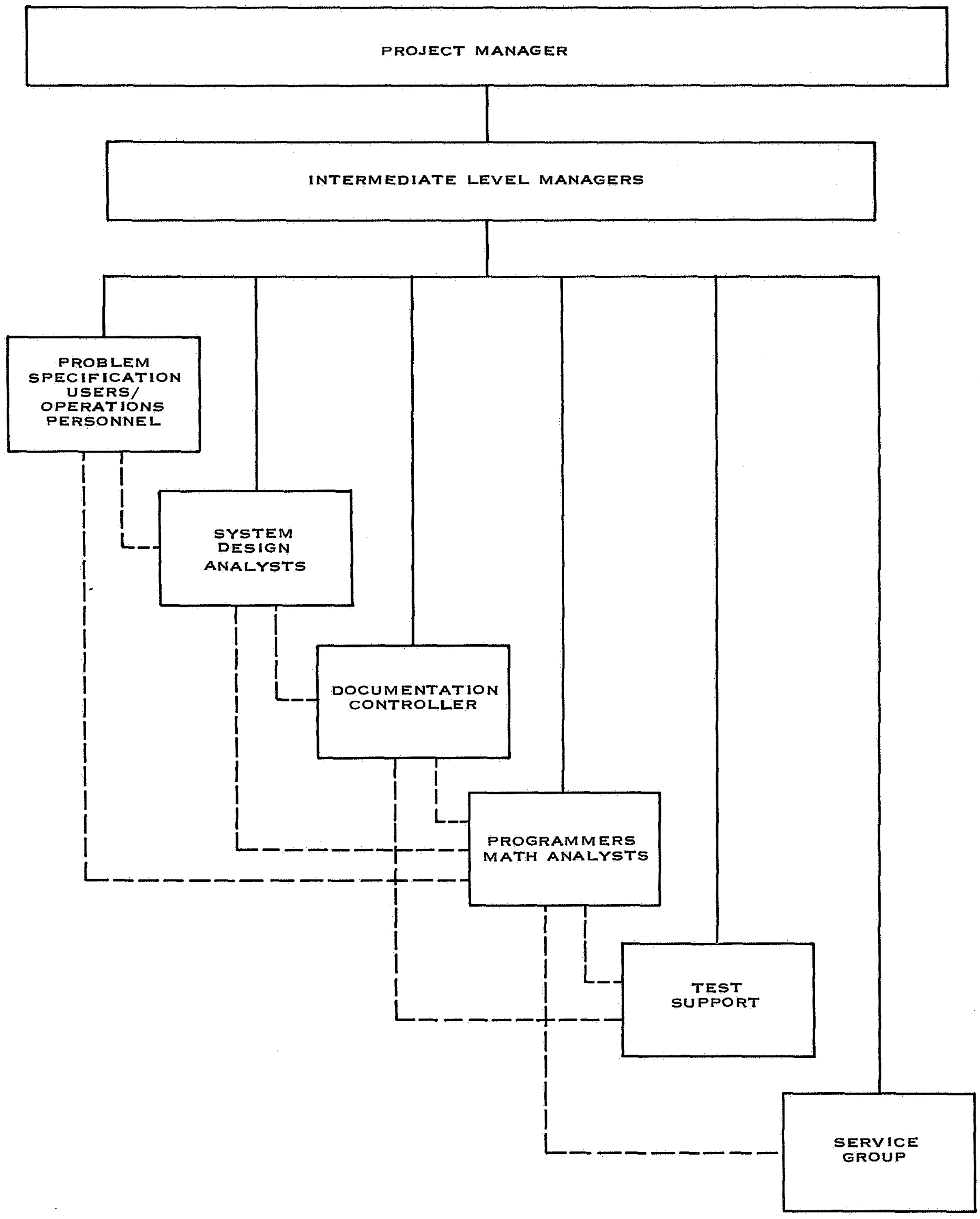

FIGURE 6.—Personnel requirements.

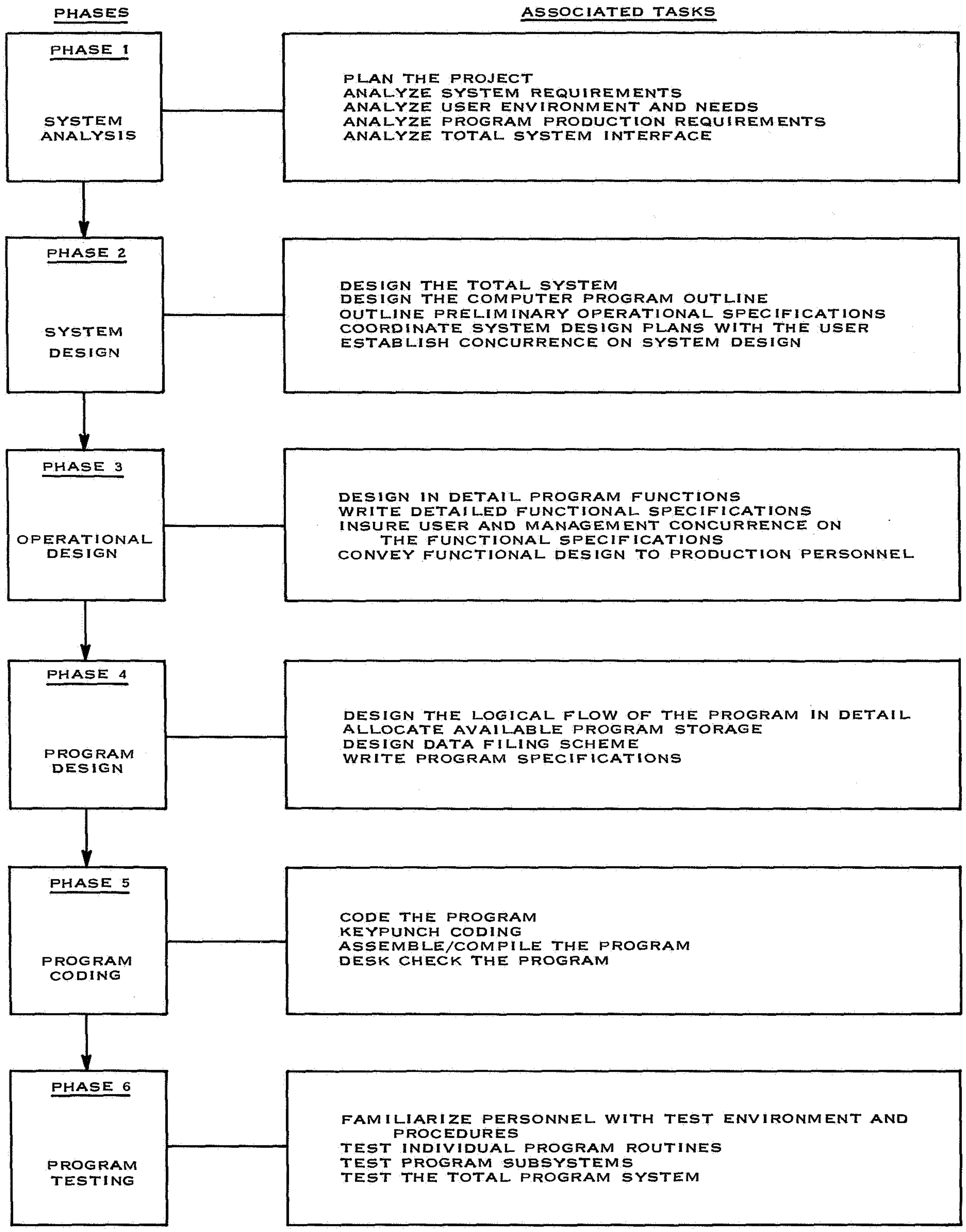

FIGURE 7.—Programming phases and tasks.

Service group personnel are needed to perform such tasks as keypunching, printing, and computer operating. The quality and organization of these service groups will affect program production rates.

Program managers are needed at various levels to supervise the activities of each of the production groups and to provide horizontal coordination support. The functions of the different task-oriented personnel listed above may overlap depending on the size and scope of the programming task. The manager needs to know what skills are necessary to complete each programming task and then he must decide how many people will be needed to finish the project in the time allotted.

Computing Facility Requirements

In deciding what resources must be made available, the manager should also consider computing facility requirements. He should estimate how much computer time is needed to complete the task. He must be aware of the impact of the reliability of equipment and support software; he should also consider travel impact and machine availability.

Software Products

In determining both the manpower and the machine time required to complete the project, an understanding of the scope of the software task is important. The required software should be produced in a manner that will lead to a product of satisfactory quality, and it should be produced according to schedules that are properly phased with interrelated schedules of system hardware. There are several intermediate and end products that, taken together, result in a workable solution to the requirements of system specifications. The products and their relationships are illustrated in figure 8.

Phases of Programming

There are no generally accepted and universally applicable descriptions of the way in which computer programs are designed, produced, and tested. There are, however, several phases and associated typical tasks in the programming production cycle. These programming phases and tasks are illustrated in figure 7. The illustrated phases and tasks are written in the context of a large visual display network, forming an integrated program that includes the receipt and processing by a computer of live data from human operators and computer output of dynamic data in response to human or automatic queries. Comparing figures 6, 7, and 8, and the resource requirements discussed above, will make relationships between tasks and resources clearer to the reader.

For small, self-contained programs all the phases shown in figure 7 are still necessary, but the system analysis, system design, and the operational design tasks are of less importance. Program testing activities are also less extensive. In addition, the coordination task is less time-consuming because one man may be totally responsible for the production of a small, self-contained program.

Cost Estimation Guidelines

One of the biggest problems facing the manager/designer of a large-scale display system is estimating the software effort. Little has been done to establish formal guidelines for estimating man-month efforts, program development facility requirements, or the dollar costs associated with the programming task. This is partly because of rapid advances in both automated display technology and visual display applications. Factors that affect computer program development costs are often unknown and, when they are known, they are difficult to quantitate. To discuss in detail all the variations in the methodology for predicting program development cost or to discuss every aspect of every cost factor is beyond the scope of this book. Nevertheless, several methodologies, some of the more important factors, and the most important pitfalls can be outlined.

In estimating the costs of future programs, a relationship between unknown future costs and past experiences must be established. Three methods are suggested by which this can be done:

(1) Compare the known costs of existing program items to similar items in each phase of

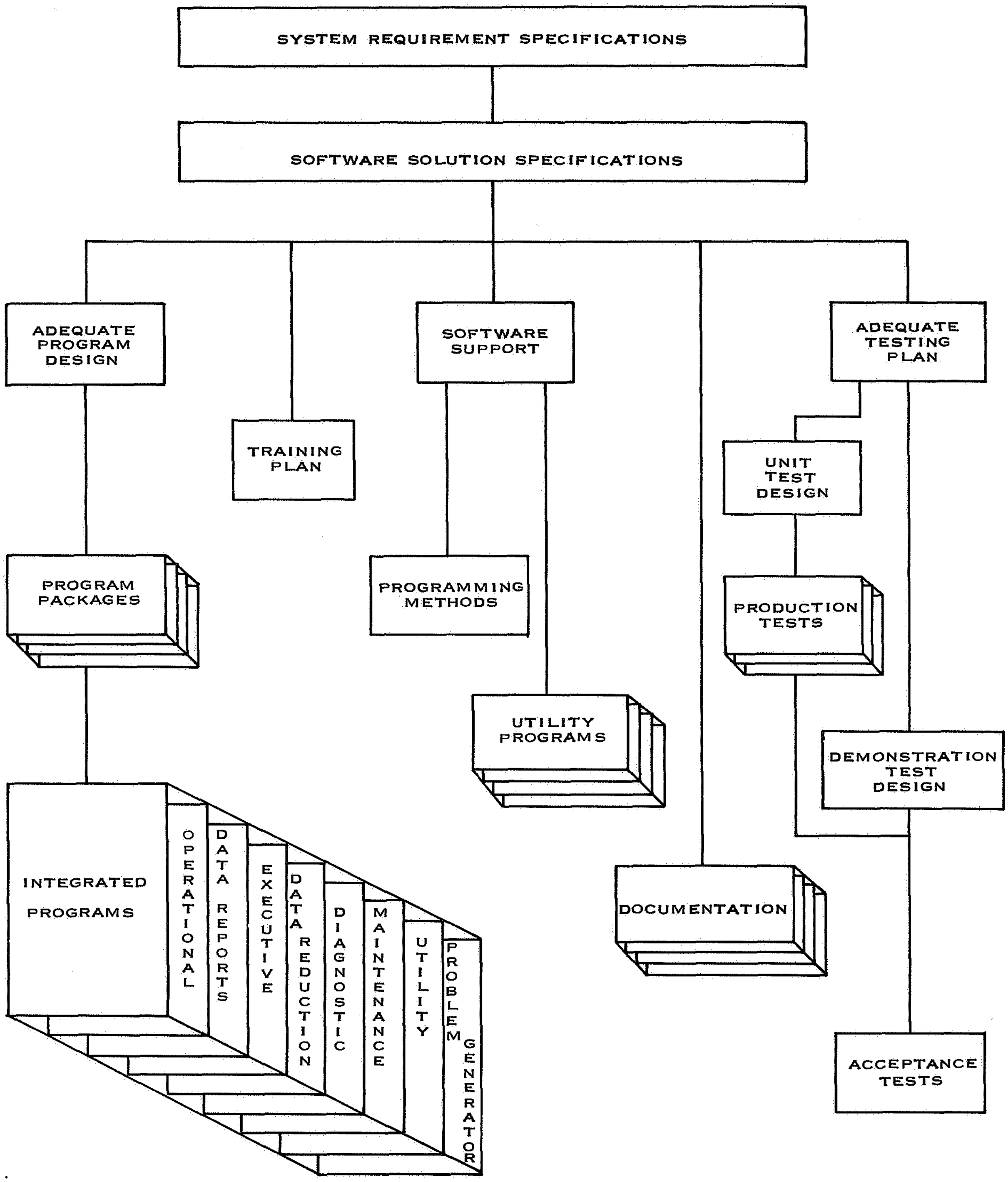

FIGURE 8.—Scope of programming products.

new program development. Allow for differences in the scale of the old and new projects.

(2) Estimate the number of units in a new program, then establish unit cost based on a previously established unit/cost ratio.

(3) Use parametric equations that consider

TABLE IV.—*Typical Cost Item Comparison*

Personnel	Man Hours: Old	Man Hours: Old/new scale factor	Man Hours: New estimate
Problem specification			
Preliminary design analysis			
Program design			
Coding			
Testing/acceptance			
Service group			
Management review			
Documentation and technical reports			
User/operations review			
Subtotal			

Other	Cost
Machine time	
Equipment maintenance	
Computer cards, tapes, listing, etc.	
Publications	
Program maintenance	
Travel	
Other	
Subtotal	

Cost—old=personnel (man hours) (dollar conversion factor)+other

Cost—new=personnel (man hours) (dollar conversion factor)+other

the various characteristics of resources expected to be used.

Table IV illustrates typical items that may be compared for the first method. For unique, untried systems, similar items may be difficult to match. As experience levels rise, however, and the data base of information relating to item costs grows, this approach may produce fairly accurate estimates.

The second method may be most helpful in estimating effort levels after the functional program specifications have been written. Once good program specifications have been written, the program can be broken down into logical units. Although the function of the separate units may differ greatly from one program to the next, the effort required to produce the units should remain fairly standard.

At first glance, the third method appears to be the most exact. Experience has taught that although the parametric equation may be scientific in form, the results are often extremely unreliable. The values assigned to the cost factors that should be considered in any parametric cost-measuring equation are difficult to establish with any degree of accuracy. As the degree of error for each of the input values increases, the confidence level of the results attained from this method becomes lower. Table V illustrates some of the important factors that affect development costs. Notice that several of the factors can be considered only after the programming project has progressed through several phases.

Each of the three methods has limitations. Their value lies in giving an ordered structure to the collection and analysis of program development cost data. If the problem of estimating

TABLE V.—*Development Costs Factors*

Program design/analysis
Amount of documentation required.
Complexity and uniqueness of required design.
Clarity and completeness of problem specification.
Design stability.
Time constraints.
Computing facility
Type of machine, capacity, language.
Turn-around time.
Equipment availability.
Programmer travel to facility requirements.
Reliability of hardware.
Closed or open shop.
Software support dependability.
Availability of debug tools.
Personnel
Stability.
Quality of training program.
Programmer quality and experience.
Client experience.
Number of people involved.
Service group organization and quality.
Environmental
Organization, horizontal, vertical.
Communication system between agencies.
Number of agencies involved.
Priority for resource procurement.
Priority of tasks (interruptions).

computer programming costs is approached independently, the resultant predictions can be lent greater confidence. By comparing new and past program tasks with respect to functional items, by breaking a new program into logical working units where similar items cannot be found, and by using cost parameter data to adjust the similar item and logical unit predictions, one can make even more accurate estimates.

Several factors that contribute to computer programming costs deserve special attention because the manager can either predict their values accurately or can control their influence.

One of these is feedback. Man-hour and computer-time requirements are often difficult to predict accurately early in the program production cycle. If dynamic feedback guidelines are established, originally uncertain data can be verified or adjusted. Figure 9 illustrates typical feedback flow.

Close attention should be paid to the tools available to the programmer. Good program debugging tools can save the programmer many frustrating hours. The computer maintenance schedule can have a direct effect on the time the programmer wastes on searching for a program bug that turns out to be a hardware fault.

Excessively long turn-around times can also adversely affect production schedules. Often a programmer cannot continue working until a compiled listing is returned from the computer shop. Good computer and auxiliary equipment maintenance and sound computer use scheduling can overcome this problem.

Such previously discussed factors as the completeness of early design documents, the accuracy and thoroughness of program documentation, the stability of manpower, and the control and quality of service groups, can also serve as valuable indicators of what is causing production slippages.

Each manager is certain to find many conditions peculiar to his project. But a basic understanding of the principles of the programming process, a knowledge of those factors that affect the process, and how and why those factors vary, makes managing the software problem much less difficult.

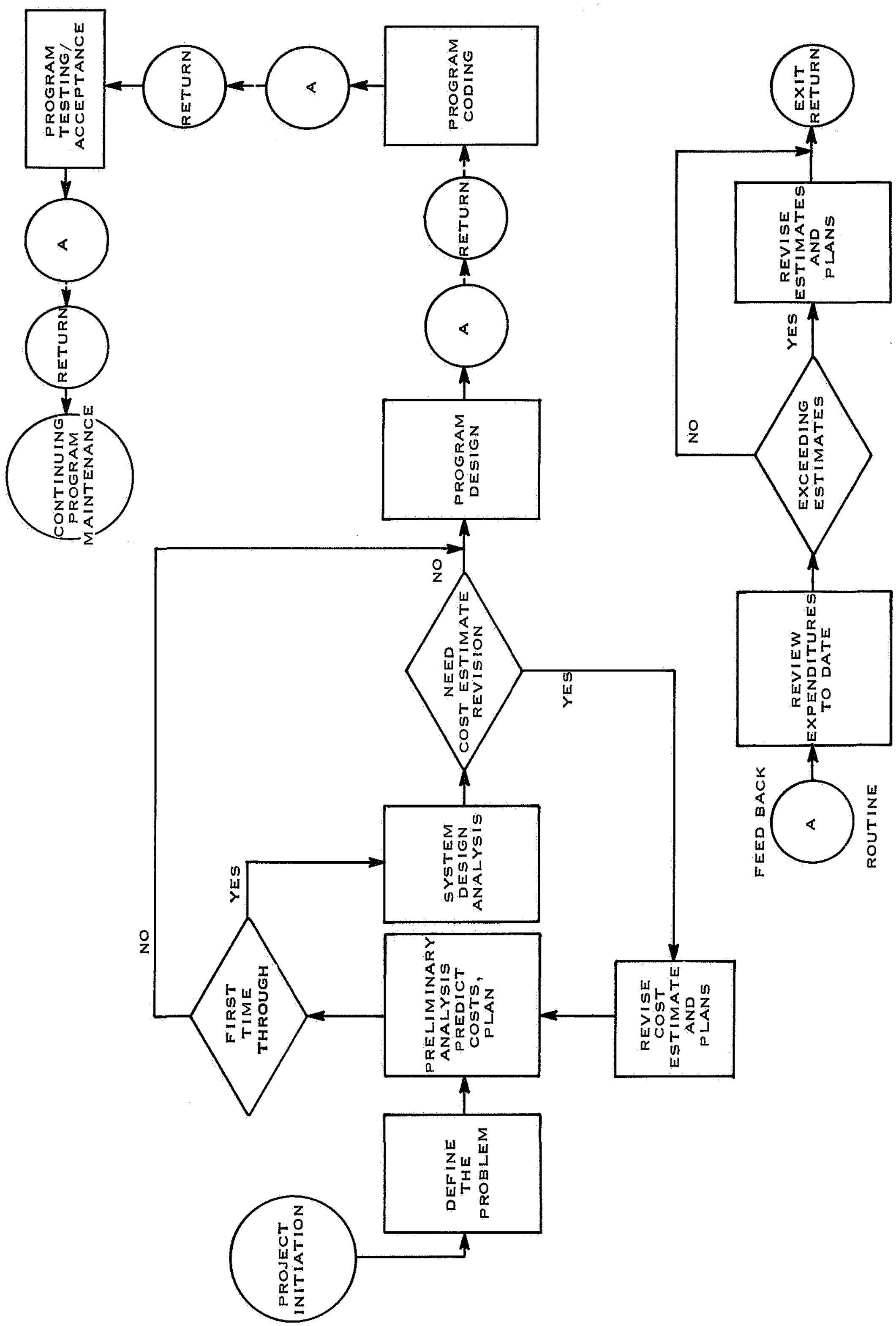

FIGURE 9.—Management feedback flow.

Managing the Software Problem Bibliography

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CHAPTER IV

Large-Scale Checkout, Ground Monitor and Control Systems

NASA uses more display equipment in support of manned spaceflight than in any of its other activities. This chapter covers the display aspects of equipment checkout, ground monitoring and mission control.

The overall information system of which the display equipment is only one part girdles the Earth. It includes communication with recovery forces, telemetry stations and remote site display equipment. It also includes a diverse array of computing power and information storage and retrieval capability. It includes specialists of many kinds, from propulsion experts to flight surgeons, whose knowledge is essential and who must be kept informed of the mission status on a real-time basis. The mission begins with the equipment checkout.

The checkout process is lengthy. Months before public awareness of the countdown the checkout process is underway. It begins during initial assembly on the manufacturer's floor. It continues with the arrival of the launch elements at Cape Kennedy and with the mating of the spacecraft and the launch vehicle. Then, when every parameter has been measured and every simulation is complete, the final countdown begins.

During countdown the entire communication network is checked. The recovery forces steam to their assigned positions. Each detail is checked again. Each specialist is concerned only with his particular data—blood or fuel pressure, heart rate or yaw rate. After ignition the connectors fall away and the vehicle rises from the pad. Ground monitoring, having been an integral part of the checkout, continues as the primary monitoring facility.

CHECKOUT

During each phase of the checkout operation, information is collected and recorded for study. In some cases it is compared with predicted values. In other cases it will serve as the reference data should a problem arise during actual flight. At the John F. Kennedy Space Center (KSC), a Central Instrumentation Facility (CIF) collects and disseminates test data. Data enter the CIF both by the umbilical connections to the vehicle and by telemetry. Other NASA centers are connected to the CIF over high-speed data links. They have independent computer installations that monitor the data stream from the CIF and interrogate to obtain special data as the result of scheduled or special program requirements.

Checkout information is monitored both at KSC and at the Huntsville Operations Support Center (HOSC) of the Marshall Space Flight Center (MSFC). Both centers maintain large-screen display rooms as well as individual consoles.

MSFC is responsible for vehicle propulsion. It is more efficient to transmit information over broadband data links than to transport hundreds of specialists who may be involved only for a few minutes at a time over widely spaced intervals. The description that follows has been adapted from the accounts given in the 1966 and 1967 annual reports of the NASA Information Display Working Group by Mr. James Felder.

The Launch Information Exchange Facility (LIEF) is a multi-purpose data display, monitoring and control facility for two-way transmission of operational data between KSC and MSFC (fig. 10). The MSFC terminal is HOSC.

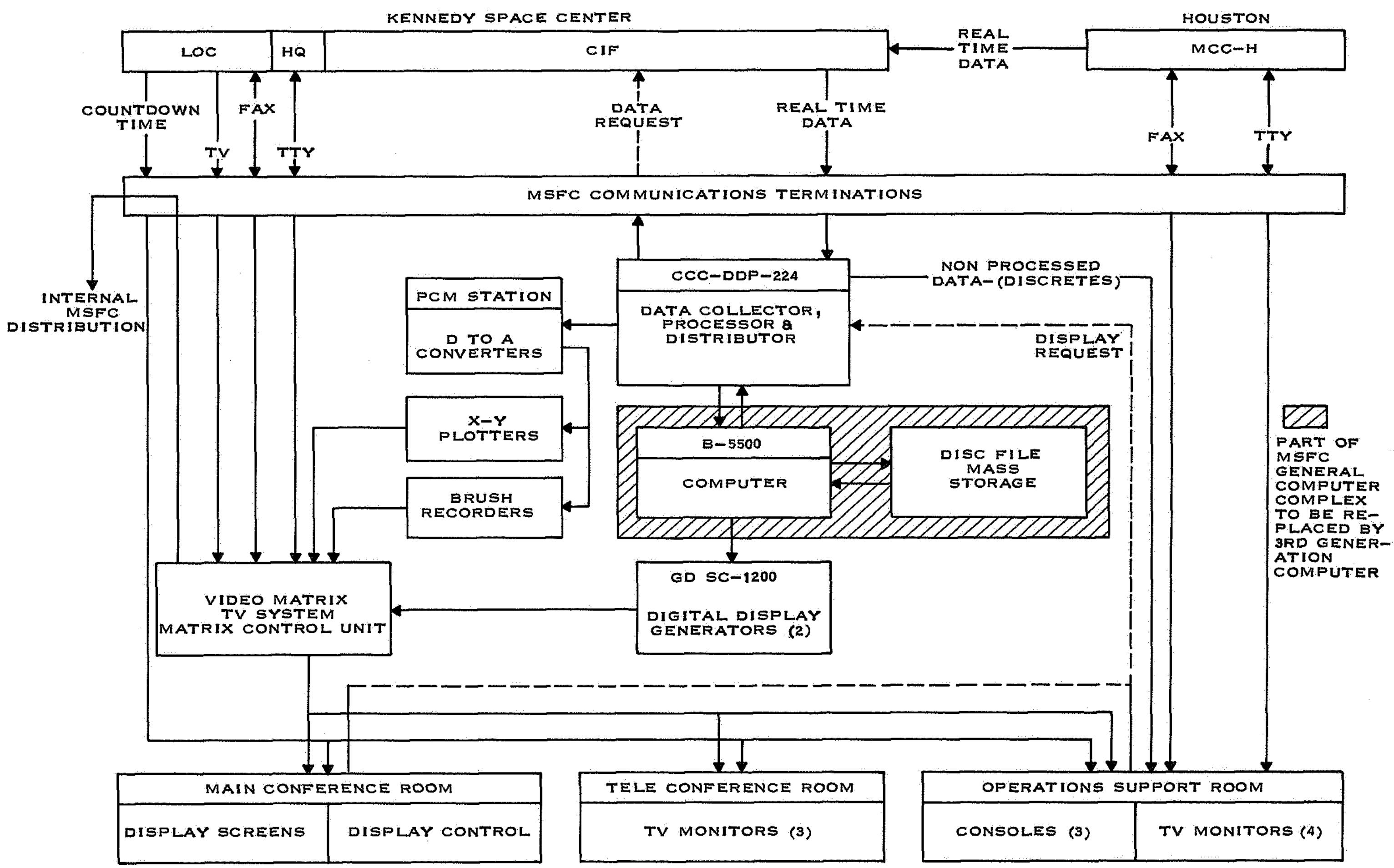


FIGURE 10.—LIEF/HOSC display system. This system provides the Marshall Space Flight Center with information required to monitor propulsion systems during checkout, powered flight, and orbital flight as well as for postflight analysis.

Electrically, the system was built by overlaying a programmable control system on an existing integrated data reduction system and providing the data reduction system with visual output devices.

Data processing for the system is accomplished in a Burroughs B5500 dual processor computer. Interfaced to the B5500 is a complement of analog-to-digital converters, cycle counters, PCM telemetry inputs, 0.1 percent digital-to-analog converters, and a high speed TV output printer plotter system, all through a small general-purpose computer. The small computer is referred to in the system as the "Collector-Distributor" and provides control for all display functions in LIEF/HOSC. It performs no arithmetic functions but serves as a "traffic cop" for all data flowing in, out, or through the system. Interfaced to this is a complement of 1.0 percent digital-to-analog converters, switch matrices, discrete light drivers, and all devices of the system requiring logical control.

The visual output devices are mounted in, or terminate in, three modular display consoles and a variety of television monitors. The consoles are equipped with discrete lights, meters, strip-charts, TV monitors, and a teletype I/O connected to the Collector-Distributor.

Data may be entered into the system in any telemetry format, from magnetic tape, card, manually, etc., from cable or off-the-air, or commercially available Bell System Data Circuits. The primary input is a 40.8 kilobit circuit from the CIF at KSC. The system has full access to the KSC data system and can address any 400 10-bit words from the CIF data-core system at will.

The system is currently programmed to handle prelaunch activities, flight operations support, and postflight data analysis. The system is organized for a "monitor and advise" function. No command functions are provided for.

Existing display devices, except large screen projectors, are in three engineers' consoles designated "Vehicle Networks," "Propulsion," and "Guidance and Navigation." There are three black and white, large screen television projectors for large group displays. Distributed among the consoles are:

Meters, 5%	90
Meters, 2%	240
Discrete lights (50/panel)	1250
Discrete lights (72/panel)	216
Decimal displays	18

Each of the consoles also contains two television monitors displaying computer-generated formats and camera output. Approximately 20 cameras in the system can present PCM telemetry plots, printer output, etc., to these monitors. The computer-generated formats are provided through two General Dynamics SC-1200 Charactron generators, and two additional outputs are on contract for this subsystem. All video equipment is 525-line EIA standard, but with 10-MHZ video bandwidth.

Modernization of the installation currently underway includes replacement of the B5500 by Univac 1108's and the procurement of two additional display devices. The first device is a digital display generator system manufactured by Monitor Systems, which will replace the two SC 1200's by 10 independent video channels. The other device is a film projection plotter system that scribes characters in opaque film.

The MSFC performs an important role in the prelaunch powered flight, orbital and postflight phases of a mission. The display system makes it possible.

When a spacecraft arrives at KSC, it is assigned a special checkout location on the test floor and a corresponding control room. This room contains the specialized test equipment required, such as plotters and meters. A few CRT displays may also be used. There is no need, however, for large-screen display equipment until later in the mission when the mating with the launch vehicle has taken place. After the spacecraft and rocket stages have been joined in an assembly area or are on the pad, connection to the data network takes place and the large launch control room and other display areas come into use.

The display equipment at KSC is basically similar to that of the Marshall Space Flight Center; however, it includes a working Digital Display System manufactured by Hazeltine Corp. The description of the DDS given below has been taken from the attachment to the 1967 annual report of the Information Display Working Group.

The digital display system, shown in figure 11, accepts computer-processed telemetry data and converts this information to a form suitable for presentation by standard video equipment. In operation, requested data are transmitted from the computer to the input buffer and then transferred at the proper rate into the display generator. The digital display generator converts the data into an alphanumeric and/or graphic format for video display. A drum memory is used to store and refresh 10 independent display channels at a rate of 30 frames per second, thus alleviating the computer workload. Flow diagrams, block diagrams, circuits, nominal values, and other general information are stored on 35mm slides where a scan converter transforms the information to a video format. A magnetic drum is used to store background information, i.e., maps, charts, and nominal curves, which may be superimposed directly onto the computer output data. Other forms of data, such as Apollo S-IC flight TV and commercial TV, are already in suitable format and may be interleaved directly into the system. The video format

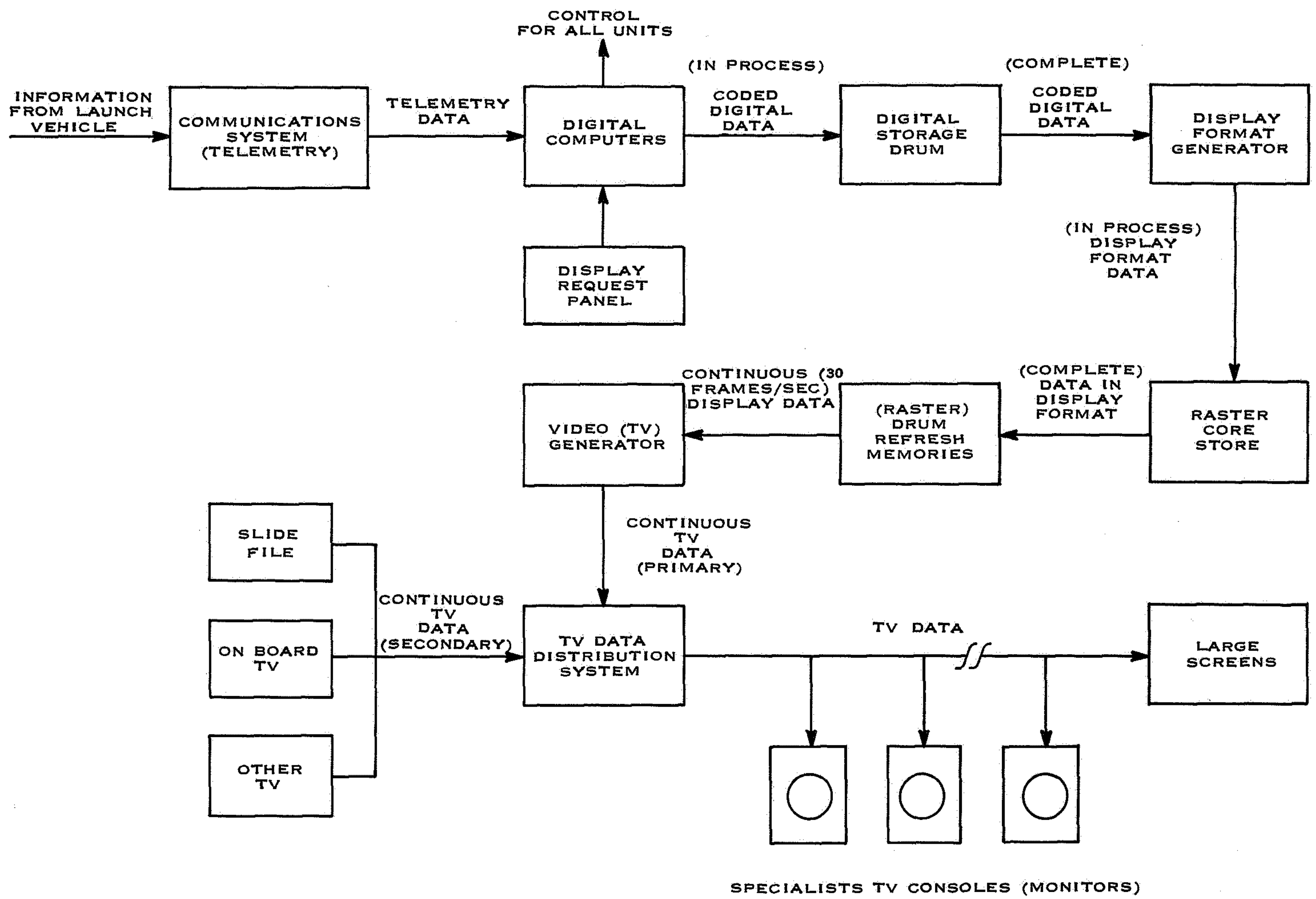


FIGURE 11.—Data display system. A block diagram of the equipment for accepting data from the launch vehicle, processing it, and making it available on TV monitors for specialists involved in a launch vehicle checkout (countdown procedure) at Cape Kennedy, for example, for Gemini missions.

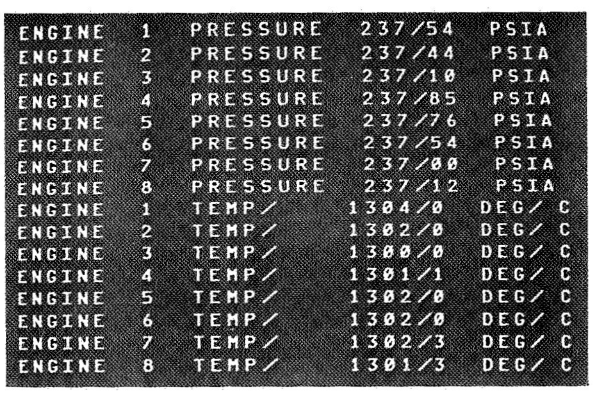
is then displayed on standard video monitors at consoles and projected onto large screens with TV projectors. Controls at the console allow the operator to select and expand the time base of the data displayed on the monitor as required.

Data are requested from the computer via the display request panel. Data can be requested either in the graphic or page-format mode. Sixteen lines of data may be displayed on a page and any line may be changed independently. The abscissa, or time base, of the graphic display, as well as digital background plots, charts, and slides, is selectable from the panel. Typical page format and graphic format displays are shown in figures 12, 13 and 14.

The data request is transmitted from the display request panel to the data request receiver. The receiver formats the message and sends the request to the computer as four 36-bit words. The request message is processed by the computer, and the requested information is transmitted as one 36-bit word to the interface logic where it is stored in the proper buffer memory depending upon which panel originated the request. From the buffer memory, data are then transmitted to the digital display generator.

The digital display generator (DDG) accepts digital data from the buffer memory and converts these data to TV video signals which, when applied to a standard 525-line TV monitor or projector, produce alphanumeric or graphic displays. The DDG has the capability of storing 128 independent symbols and 8 grids, drawing vectors any length, and shifting the display. Characters and grids are stored in a magnetic core memory and thus may be changed readily. Each DDG can display 10 independent channels of data.

The system control examines the computer word to determine in what mode the DDG will function, i.e., character generation, vector generation, grid displays, or shift. In the character mode, the proper character is retrieved from the character storage (word by word), and transferred to the raster core storage. After the entire picture is generated in the raster core storage, it is transferred to the drum refresh memory. The drum refresh memory is capable of storing 10 independent displays and updates these displays at the 30 frames/seconds video rate. The data are transferred from the drum as parallel words into shift registers where they are shifted serially at a 20-MHz rate. Timing is recorded on the drum and decoded so that the shifted serial data are formatted into a standard 525 scan-line video picture. In the graphic mode, data are processed in a similar manner except that the appropriate grid is added to the display. Graphic format grids are loaded into the raster core storage as a dot-by-dot pattern after vector slope and length are deter-



ENGINE	1	PRESSURE	237/54	PSIA
ENGINE	2	PRESSURE	237/44	PSIA
ENGINE	3	PRESSURE	237/10	PSIA
ENGINE	4	PRESSURE	237/85	PSIA
ENGINE	5	PRESSURE	237/76	PSIA
ENGINE	6	PRESSURE	237/54	PSIA
ENGINE	7	PRESSURE	237/00	PSIA
ENGINE	8	PRESSURE	237/12	PSIA
ENGINE	1	TEMP/	1304/0	DEG/ C
ENGINE	2	TEMP/	1302/0	DEG/ C
ENGINE	3	TEMP/	1300/0	DEG/ C
ENGINE	4	TEMP/	1301/1	DEG/ C
ENGINE	5	TEMP/	1302/0	DEG/ C
ENGINE	6	TEMP/	1302/0	DEG/ C
ENGINE	7	TEMP/	1302/3	DEG/ C
ENGINE	8	TEMP/	1301/3	DEG/ C

FIGURE 12.—Displayed data. This is an example of the TV console displays for specialists using the DDS system of figure 11, in this case giving data on the launch vehicle engines.

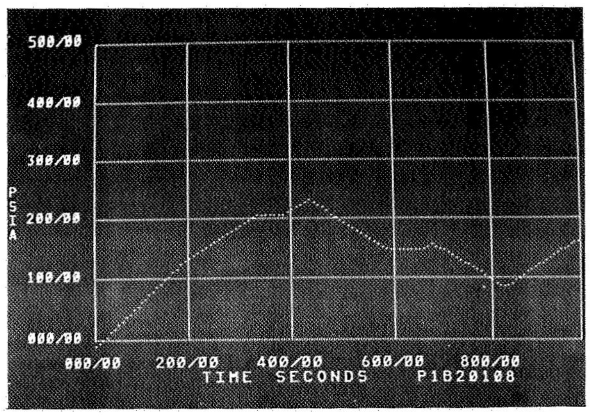


FIGURE 13.—Plotted data. Data may be displayed in the tabular form (fig. 12) or as shown here plotted as a function of time.

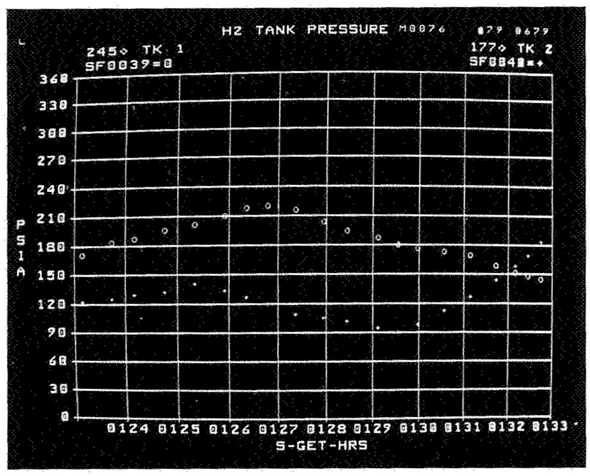


FIGURE 14.—Typical fuel display. The grid is provided by a 16-mm slide and the data showing the pressure status in two different tanks are provided by a computer that prepares the data for display. The circles and crosses distinguish the two data sources.

mined from start-stop coordinates by an arithmetic unit in the vector generator. To avoid 30 frame per second flicker, the grids are displayed at half intensity. A shift feature allows graphic form data to be moved left across the display screen eight bits at a time during each computer update. This capability allows the observer to have a strip-chart-like data presentation on his display device.

CONTROL

The checkout display systems, naturally through telemetry, carry over into a ground monitoring function. The significant difference between ground monitoring and checkout is not the communications, but the fact that interruptions for reconsideration or repairs are impossible while the mission is actually in space. The Mission Control Center of the Manned Spacecraft Center in Houston serves as a ground monitoring system, but it also serves as a control system. The difference between a control system and a monitor system is not clearcut from the viewpoint of hardware, but the intention is clear in the case of the MCC.

To increase the probability of attaining the mission goals and to maintain flight crew safety, the Houston Mission Control Center (fig. 15) provides the overall control of activities from the beginning of countdown through flight and recovery. It exercises direction and control over the manned spaceflight network (a worldwide system of communications and people to provide the necessary support to the Mission Control Center) and, more important, transmits information, advice, and recommendations

FIGURE 15.—Houston Mission Control Center. A large communications system accepts data and transmits voice and digital commands through a global network of tracking and communications stations. The heart of the system is the real-time computer complex controlling data flow between the communications system and the display and control system. Pictured is a moment during the Gemini-Titan 4 spaceflight on June 3, 1965.

to the spacecraft crew concerning the appropriate action to be taken. It also controls certain aspects of flights of unmanned vehicles as part of the manned programs. Control is unambiguous in the case of unmanned flight. Manned flights, except during a limited period, are under control of the astronauts. The ground can control certain telemetry equipment but ultimate control is in the hands of the men in space. This is best illustrated by the fact that each section head of the MCC team is equipped with an illuminated pushbutton labelled "Abort Requested." The mission director, however, has only a light.

The mission control team consists of the mission director, flight and recovery control, and staff support (fig. 16). The primary facility is the control center with which we are concerned here because it contains the display equipment necessary to the efficient performance of the control display system function. As part of the Mission Control Center, the display control system (fig. 17) provides the link between the mission control team and the personnel and systems actually performing the mission. All information necessary for monitoring and control of the mission is passed through a real-time computer complex connected to the display control system by the computer interface. The computer interface, in turn, connects to group displays and to digital-to-television converters, a TV subsystem and then to consoles. The consoles supply control information to the computer interface.

As in the checkout control center, the heart of the display system at Houston is a television system that provides data from many sources at any one of a large number of consoles. Preparation of computer-generated data for display by means of the television system is provided by composite optical images (fig. 18). The charactron is a shaped-beam cathode-ray tube that converts data in coded form from the computer into the image form of alphanumeric characters, symbols, and lines. In addition to compu-

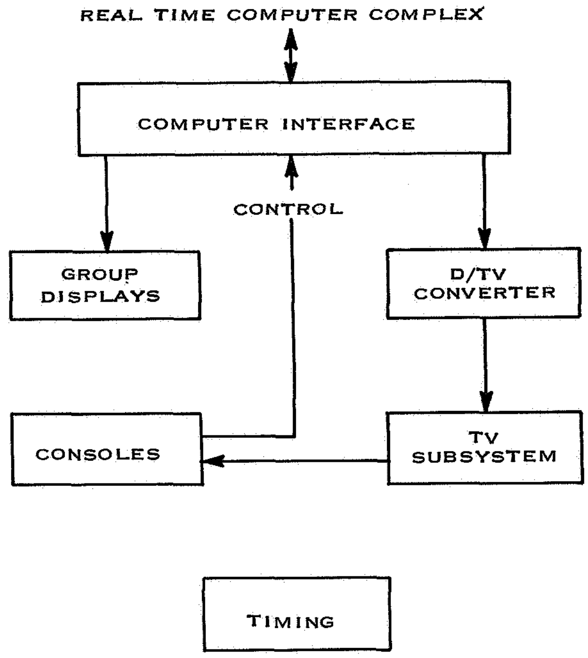


FIGURE 17.—Display control system. Group displays (large-screen displays) and console displays (using a digital-to-TV converse system) interface with the real-time computer complex to accept data and to transmit control data.

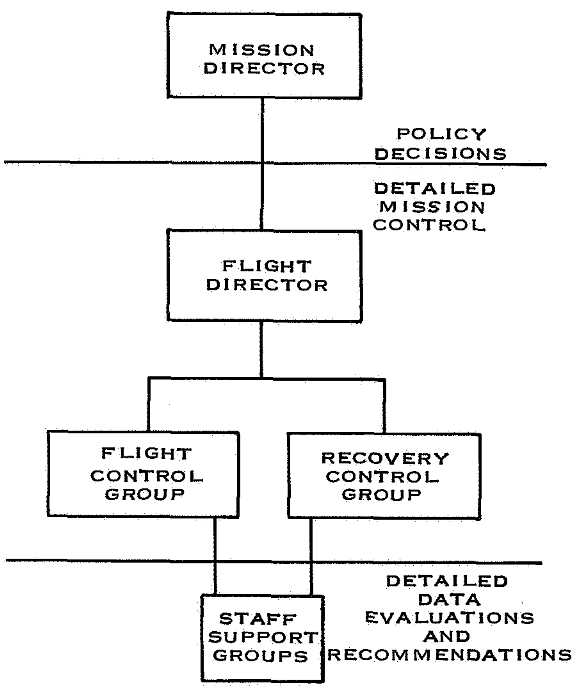


FIGURE 16.—Mission control team. The mission control team, by its diverse nature, depends heavily on the Mission Control Center during space flight missions.

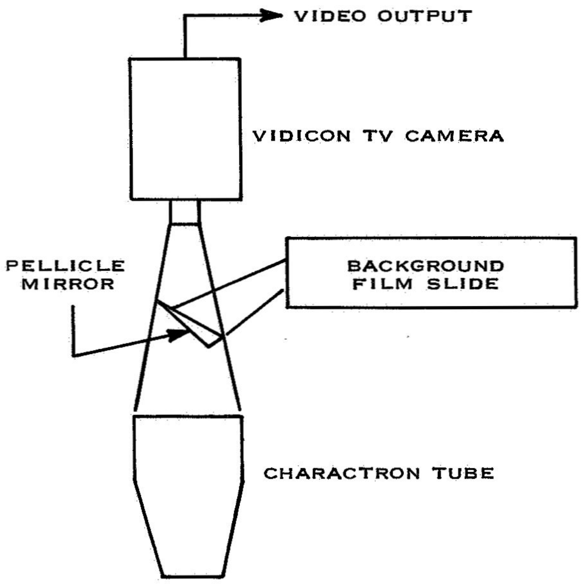


FIGURE 18.—Composite optical image. Both computer-processed data via a charactron tube and background film-slide data can be transmitted (separately or superimposed to consoles via a vidicon TV camera).

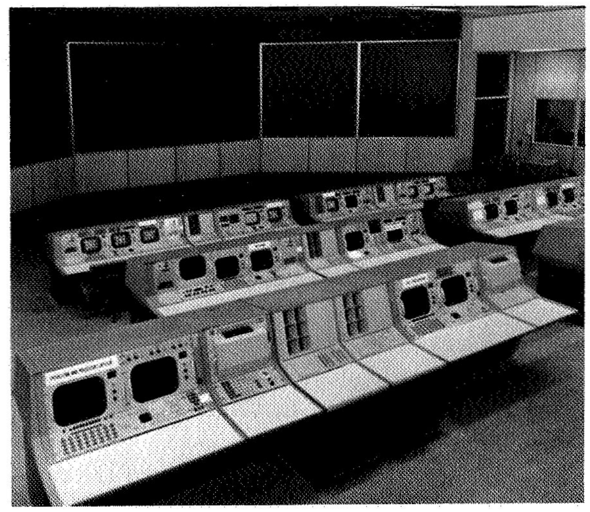


FIGURE 19.—Control Center. Interior view of the Mission Control Center, Houston, located in Building 30, showing the forward area of the Mission Control Room with the orbital tracking board and consoles. The MCC is the center of a huge global network of tracking and communications stations providing centralized control for the Gemini space flights.

ter-generated data, background film slide information is available through multiple slide access mechanisms. A pellicle or half silvered mirror allows superimposition of the computer-generated and the background data. A vidicon TV camera converts the image formed by the charactron and background slide into video output.

Television distribution is provided by a video switching matrix under computer control that allows a console operator using a manual selection keyboard to select video from any one of 70 sources.

Mission control center consoles are shown in figure 19. The console subsystem provides consoles and all the equipment thereon. Every console has two television monitors for adequate display capability and reliability. Each console includes, in addition to the television monitor, various lamps and switches necessary for monitoring and control. In addition to consoles, there are various group displays in the operations control room of the mission, the heart of the mission control center (figs. 20 and 21). The group displays provide wall-type displays for the mission director and his staff that consist of three Eidophor television projectors, two projection plotting displays, and group time and digital readout displays.

Development efforts for the display systems of the Mission Control Center involve both hardware and software. The following is excerpted from the annual reports of the Information Display Group descriptions of some of this work as presented by Mr. Oscar Patterson of the MSC Information Systems Division.

The Digital Television Display System (DTDS) is an all-digital system with performance characteristics that will offer second-generation improvement over the present MCC–H displays in accuracy, content, control and appreciable advantages in space, power, cooling and maintenance requirements.

The system is completely modular and easily expandable on a channel-by-channel basis from its initial 8 channels to 64 or more independent outputs.

Background information will now be supplied from a digital background generator retaining the precision of the basic system and eliminating the need for photographic slide files used in the present MCC–H display system. In addition, new man-machine control devices are provided to allow the operator real-time access to the display channels for format generation, editing, data flagging, and message generation. These devices include symbol keyboard, tracking balls, Grafacon tablet, and function and category selection panels. The formats can be modified in either an "off-line" or "on-line" mode.

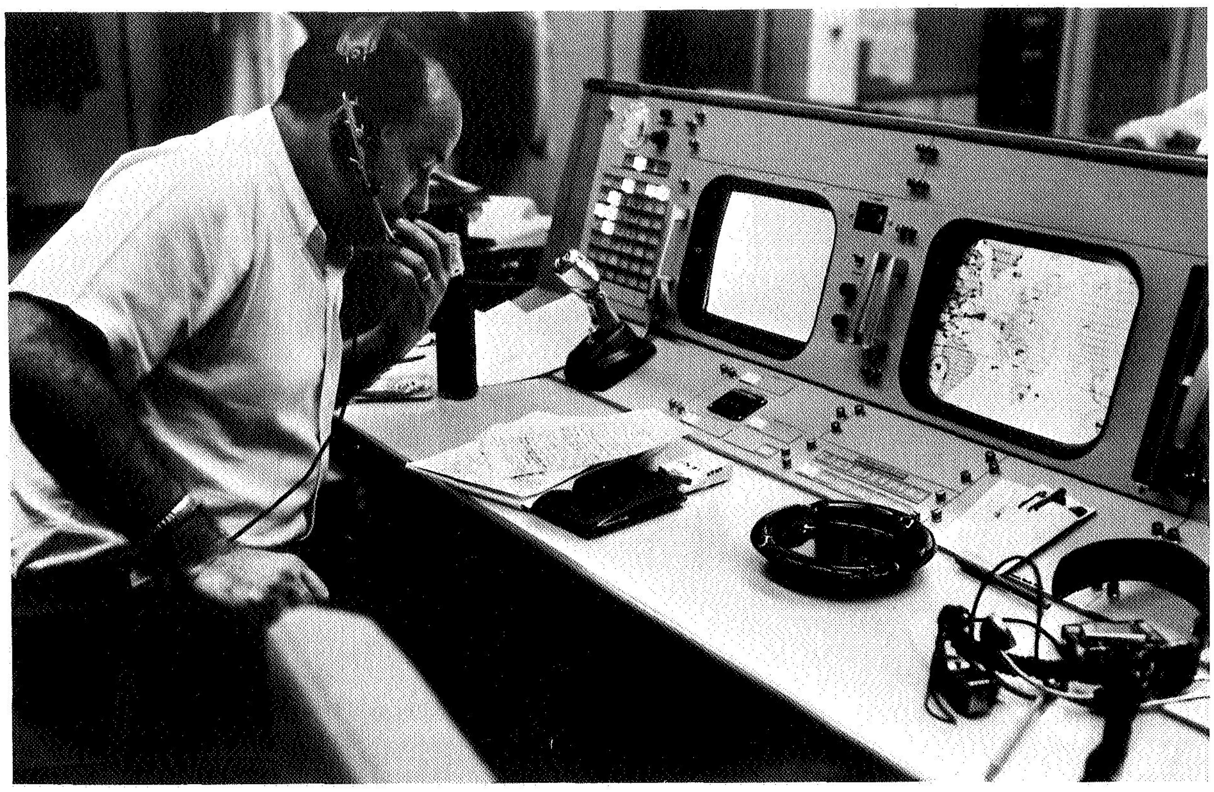


FIGURE 20.—GT–4 simulation. The MSC Public Affairs Officer is shown at his console in the Mission Operations Control Room in the Mission Control Center, Houston, during a Gemini-Titan 4 simulation. The simulation was a training exercise to prepare for the 4 day, 62-orbit GT–4 flight scheduled on June 3.

The video recirculation memory is provided by delay-line units. This storage not only is used to refresh the video displays at a 30-cycle frame rate but also allows storage of the computer data from which the display was derived. At any time this computer language display information may be recalled by the computer for additional processing.

The DTDS is designed to operate in a 729-line television system. This line rate provides the high resolution necessary for Mission Control Center application. The DTDS is capable of displaying computer-generated data on either black and white TV monitors or in combinations of seven colors on color monitors. No equipment modification is required for using any channel in either the color or black and white mode. All channels are assigned by the computer through the coding contained in the computer words.

In addition to the DTDS, development of a high-quality color television monitor has been achieved. This unit provides 1000-line horizontal resolution and 800-line vertical resolution. It operates in 945, 729 or 525 TV line rates and provides seven colors: white, red, green, blue, cyan, magenta, and yellow. A high-quality color Eidophor projector development has also been funded.

The demands on and the capabilities of the NASA display systems have grown steadily from the first suborbital flight through the Mercury, Gemini and Apollo projects. The growth has been orderly and planned. The experience gained is being summarized in the form of technical guidelines. One such guideline for all-digital computer driven displays was prepared by the Manned Space Flight Information Display Working Group.*

* Specification Guidelines for All-Digital Computer Driven Display, National Aeronantics and Space Administration, July 1967.

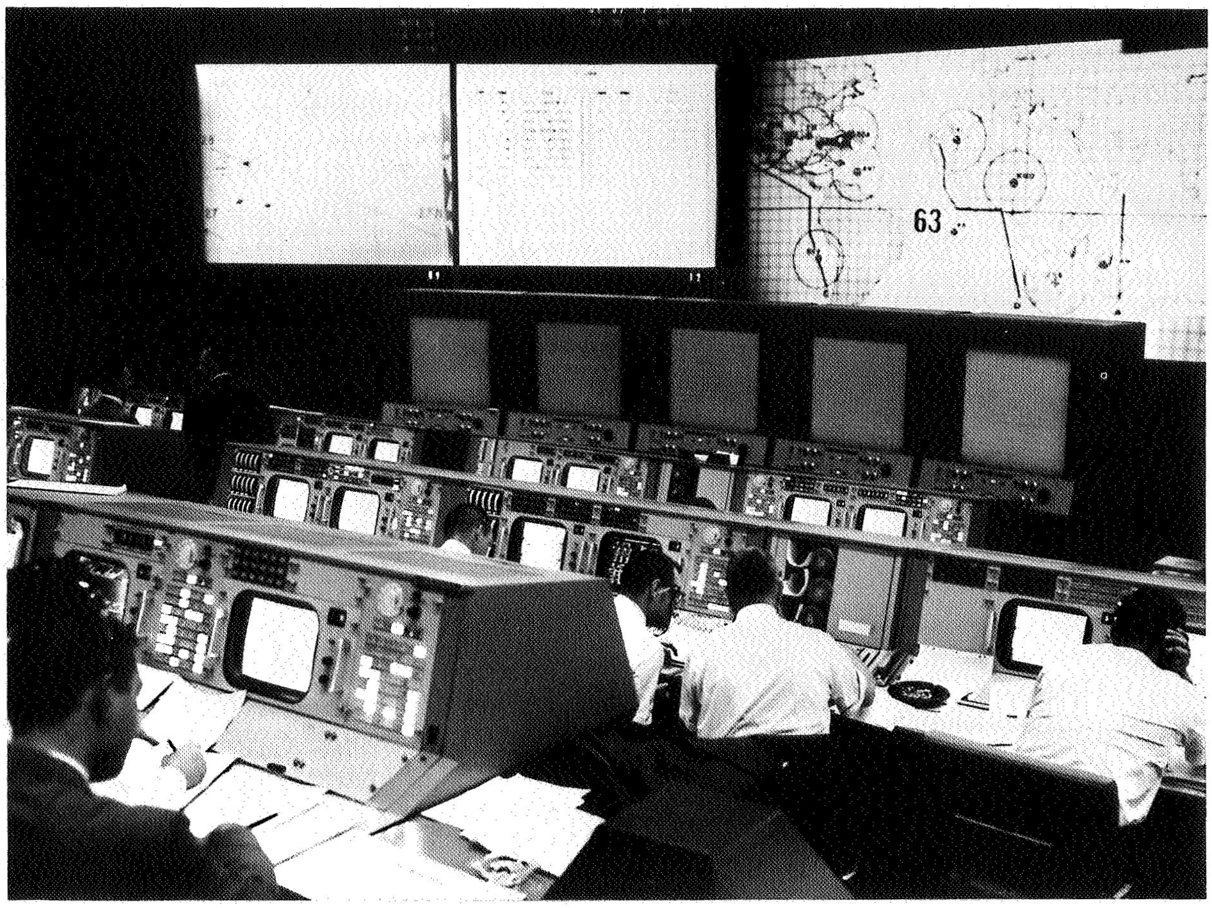


FIGURE 21.—Gemini 4 mission control. Overall view of the Mission Control Center after the Gemini 4 spacecraft made a successful splashdown in the Downrange Recovery Area in the Atlantic Ocean. The plotting board at right shows the Gemini 4 spacecraft as it was in the beginning of its 63rd revolution of the earth as it made its successful reentry into the earth's atmosphere and finally to the splashdown. The MCC served as the center of a huge global network of tracking and communications stations that provided centralized control for the Gemini mission.

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CHAPTER V

Interactive Display Systems

Interactive display systems extend the capabilities of a man to perform complex and time-consuming tasks by giving him a direct view of computer outputs and allowing him, in turn, to provide inputs to the computer. Thus, it is said that humans are interactive with the computer. Some of the most important display work in progress over the last 10 or 15 years has been in this area.

Interactive systems as exemplified in this chapter are of three types. The first type is primarily graphic and is concerned with pictorial representations presented in various ways. The second type is primarily symbolic with graphic presentations confined to mathematical representations of functions in graphical form. The third type of system involves unstructured files to be presented and manipulated under program control. The latter type may be destined to have a major impact on corporate financial control procedures.

SCIENTIFIC AND ENGINEERING SYSTEMS

Display systems play a large part in the advancement of the computer as an aid to humans in performing scientific and engineering tasks. Improved and newly developed display equipment puts the relationship of man to machine on-line. Scientists and engineers interact directly with input-output equipment as they solve their problems, investigate new procedures, apply various solutions to given problems, and perform design tasks. Display systems insert the human directly into the processing loop by giving him a "conversational" mode of operation. Thus, the term interactive is applied because of the human and computer interaction.

Although the executive branch of industrial organizations has an analogous on-line problem in the management of files, this discussion is limited to the scientific and engineering branch with its on-line problem of design. Both applications of interactive systems are only in early stages of development, partly because the equipment is somewhat ahead of the user. The full impact of interactive systems in the scientific engineering and management communities still lies ahead.

Some of the early work in interactive systems for the technological user was performed at M.I.T. by Dr. I. E. Sutherland. His system is called "Sketchpad." In its simplest form it consists of a display console connected to a computer containing special-purpose programs that permit a man and the computer to converse rapidly and directly by line drawings.*

Sketchpad offers a form of man-machine communication in situations in which typed statements would prove cumbersome and a line drawing convenient. Sketchpad has shown that line drawings in conversational mode are applicable to many scientific and engineering problems such as:

(1) Drawing patterns, a step towards automated drafting techniques

(2) Drawing and motion of linkages to show mechanical relationships

(3) Dimensioning of drawings

(4) Bridge design by showing the distribution of stresses

(5) Artistic drawing

(6) Electrical circuit diagramming.

* Sketchpad was a project performed in part at the Lincoln Laboratory, a center for research operated by M.I.T. with the joint support of the U.S. Army, Navy, and Air Force under Air Force Contract AF19 (628)-500.

Examples of systems using these or similar techniques are given below. In the scientific area, mathematical systems form significant applications of interactive display systems. In the engineering area, design automation systems are significant applications of interactive display systems. The work in file management and related interactive systems is also closely related, although not as heavily oriented towards graphics as scientific and engineering systems.

Mathematical and design automation systems use similar display equipment. There is already a wide variety of equipment such as CRT displays with keyboard and special input devices for application in these problems. The most significant work being done today, however, is in the development of computer systems and their programs for this application of display systems. The use of interactive display systems is in most cases dependent upon the latest software developments in computer system executives, data management systems, time-sharing, information storage and retrieval, and the design of query languages.

MATHEMATICAL SYSTEMS

There are a number of conversational mode systems with the same basic goal: to give the user a variety of mathematical tools so that he may apply them to his particular problems without learning a complex computer programming system. One of these is the AMTRAN system, a multi-level language. It is being developed at the NASA Marshall Space Flight Center. It is designed for an applied mathematician with no prior knowledge of computing for programmers, or for practitioners at any intermediate level. It can be used not only on-line in a conversational mode, but also off-line in a batch processing mode or in a combination of the two. A scientist or an engineer with no background in computer techniques should be able to solve relatively straightforward mathematical problems with little or no instruction in the use of the AMTRAN system. The system includes a semiautomatic mathematical problem-solving system. It provides standard mathematical operations such as integration, numerical or algebraic differentiation, inversion, etc., in the language of classical mathematics that suffice for many of the problems commonly encountered by the scientist or engineer. The programmer and the more experienced user can construct their own programs and mathematical operators at the keyboard so as to handle problems for which the standard set of operators is inadequate. They can take advantage of the extremely short turnaround time, one of the most significant characteristics of conversational-mode programming. The AMTRAN system is also designed to be economically competitive with batch processing systems in speed and storage. This requirement is met by the use of a special programming package called an "interpretive compiler."

A key feature of the AMTRAN interpretive compiler is its ability to provide automatic mathematical translation at a higher level than the formula translation of FORTRAN. Another key feature is the user's ability to expand the facilities of the language. For example, he can define binary operators, specialized algebras, and symbol and text manipulation subroutines. A third feature concerns an effort to approach a natural-sounding English dialogue, with context-sensitive instructions, and to minimize unnecessary bookkeeping by providing dynamic memory allocation. A fourth feature consists of providing a library of higher-level operators (extended subroutines) such as SUM, DELTA and TIMES. A fifth feature is the provision for a built-in (optional) interactive graphics mode of operation. The developers claim that these programming extentions taken in toto reduce programming time (and presumably, costs) by factors ranging from 2:1 to 10:1 over conventional FORTRAN.

Mathematical equations may be entered in their natural textbook format and immediate graphical and alphanumeric displays of the results are displayed on a cathode-ray tube display scope and a typewriter. For example, a non-linear differential equation can be entered in a series of steps and is typed out by the AMTRAN special typewriter in the form of the original differential equation.

AMTRAN can also be operated from low-priced teletype or typewriter terminals and is compatible with standard card and printer output media. Of course, natural mathematical formatting requires either CRT displays or special teletypes (e.g., a 37 KSR or Invac with half-line reverse-indexing). However, a part of the AMTRAN effort has gone into the development of low-cost graphics computer terminals designed around the new Tektronix 611 scope display unit. The 611 scope display represents a major improvement in storage design and promises to provide a breakthrough in graphics terminals prices. Such terminals should be commercially available in the near future for $10 000 to $15 000 per terminal.

A typical AMTRAN terminal consists of a three-part keyboard, one or two 11-inch cathode-ray tube display scopes, a Polaroid camera for the scopes, and a typewriter. A stylus or electric pencil can also enter graphical information to the computer. The keyboard has both special-purpose buttons for permanently programmed mathematical operators and general-purpose buttons that are programmable by the human operator. The typewriter, on the other hand, can call for a majority of operations and can also serve as an output device when a hard copy is needed. Two scopes are provided on some stations so that one scope can present alphanumeric information while the other retains "blackboard" graphical displays. The alphanumerical scope prints out instructions and error messages, and, while it does not provide hard copy as does the typewriter, its writing speed is much greater.

A recent article in DATAMATION describes the solution of a differential equation by the AMTRAN system. Figure 22 shows the printout of the scope face. The user has various operators such as SOLVE. These operators bring subroutines into effect. The second statement in figure 22, for example, is the procedure for solving differential equations. By typing in the mnemonic SOLVE, or pressing the SOLVE button, the computer selects the appropriate method of numerical integration.

The third instruction in figure 22 calls for a plot of the solution on the display scope face, figure 23. It is plotted with appropriate scale factors on the x and y coordinates. The origin is placed so as to make best use of the face areas.

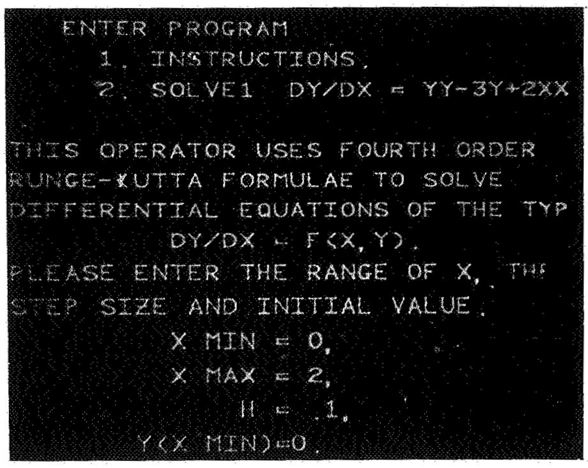

FIGURE 22.—AMTRAN system alphanumeric display. A solution of a differential equation by the AMTRAN system is entered into the computer and displayed to the operator.

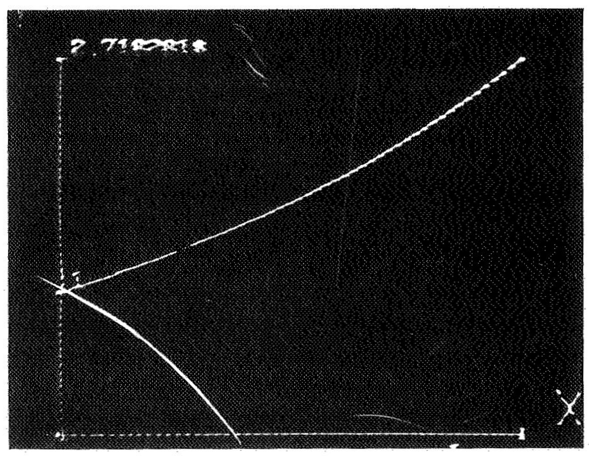

FIGURE 23.—AMTRAN system plots. The solution of the differential equation is plotted with appropriate scale factors x and y coordinates.

The AMTRAN system also can respond to questionable data points (figs. 24 and 25).

The basic inspiration for AMTRAN was the Thompson-Ramo-Wooldridge on-line computer system originated by G. J. Culler and B.D. Fried and later extended by Culler at the University of California (Santa Barbara). Other conversational mode systems are the JOSS, QUIKTRAN, MAP, RECKONER and APL. (None of these other systems currently employ graphics terminals.)

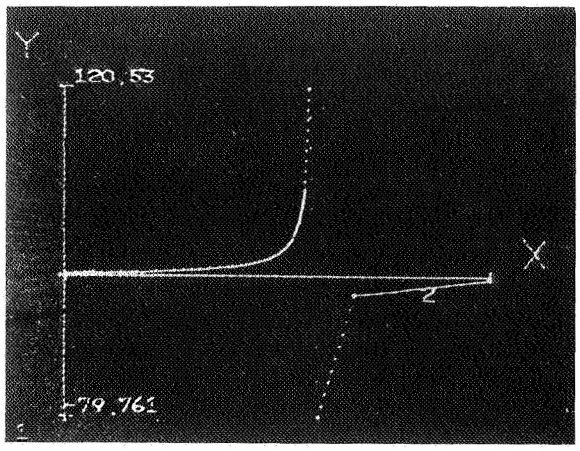

FIGURE 24.—AMTRAN system open curve. This figure shows what happens when an AMTRAN user attempts to represent a function that "blows-up" in the middle. Here the tangent of x was represented over the range from 1 to 2. Because the tangent X becomes infinite at $x=\pi/2$, a complete numerical representation is not possible.

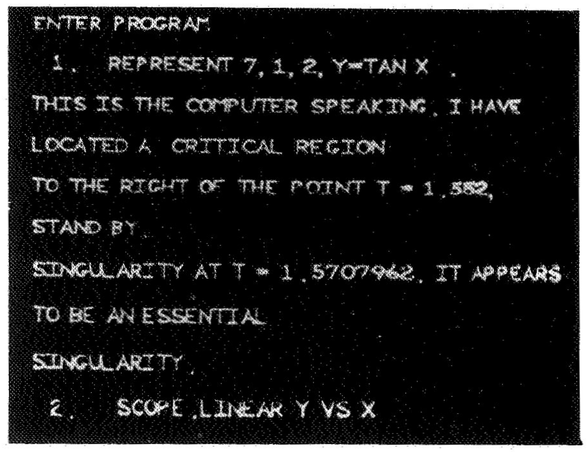

FIGURE 25.—AMTRAN system error response. This figure shows the computer's response to the curve shown in figure 15. The computer works from left to right making tests until it identifies an error condition. At that point, the message shown in this figure is displayed to the user and the system goes into a scanning mode, hunting for the focal point of the disturbance. A message is then printed-out telling the user more detail about the nature of the irregularity.

DESIGN AUTOMATION SYSTEMS

In general, design automation is the application of computers as design aids to engineers, draftsmen, designers, and other technically oriented people. Production and maintenance workers also may use the output of computer programs in their work. Another term used, and one applied particularly to systems using cathode-ray tube displays, is computer-aided design. Computer-aided design (sometimes used interchangeably with the term design automation) includes those tasks in which a computer system assists the designer but does not supplant him. The man and machine often work together in real time. There is two-way communication between the designer and the computer system during the task execution rather than only at the beginning. The Sketchpad system inspired much of the work in computer-aided design. Another project that contributed to the use of display systems in engineering was the work at the General Motors Research Laboratory resulting in a system called DAC–1 (Design Augmented by Computers).

This system evolved from experience in the GMR Laboratory and from project requirements of a designer as part of a computerized design process. The designer generally approaches the computer system with a drawing or sketch in hand. He enters the drawing or sketch through a graphic console connected to a computer and the system becomes a tool for rapidly developing, modifying, and reviewing his design. As a result, he should be able to take with him (without delay) a document showing his computer-aided design in standard quality form for the next step towards production.

The equipment that originally comprised the DAC–1 system was designed and built by IBM to specifications provided by GMR. It consisted of a graphic console that included a display tube, control buttons and lights, a card reader, an alphanumeric keyboard, and a positioning indicating pencil. In conjunction with the graphic console, there is an image processor that permits computer-controlled scanning of film images and computer-controlled recording on 35mm film. A block diagram of the overall system is shown in figure 26. It consists of two parts: the CPU Complex and the 7960 Special Image Proc-

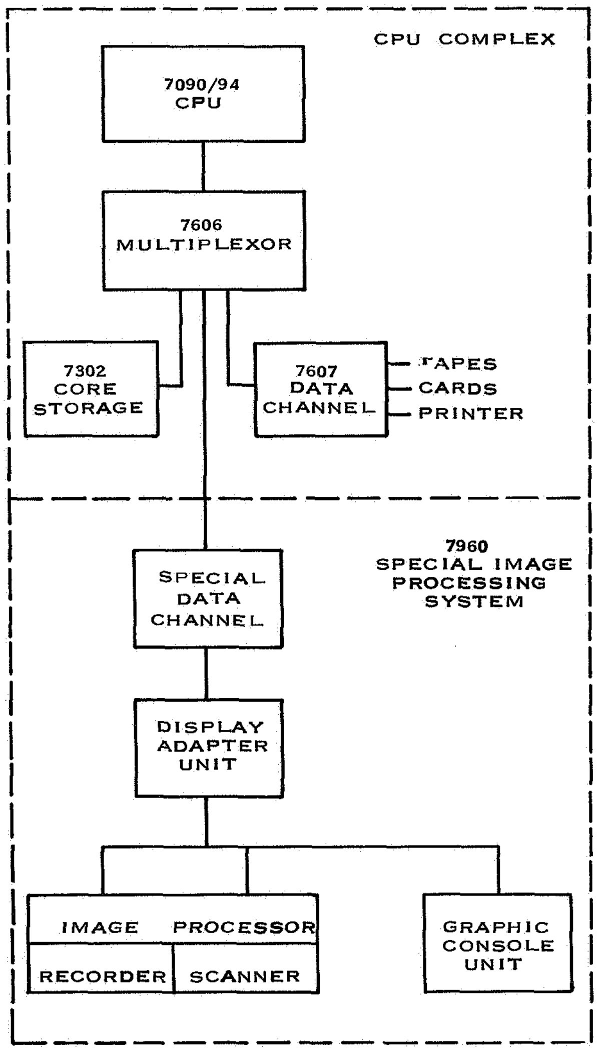

FIGURE 26.—System block diagram. The DAC–1 system is connected to the CPU complex (a standard computing system) through a special data channel in the IBM 7960 special image processing system. A display adapter unit controls the image processor for both recording and scanning and the graphic console image.

essing System. The CPU Complex is a standard computer system. The 7960 system is the specially designed DAC–1 system. It has three basic units, connected to the CPU Complex by the special data channel. The display adapter unit provides control of the basic system, control-unit selection, and digital-to-analog conversion. The image processor is the film input and output unit for data in graphic form. It contains a CRT photo recorder, projectors, CRT photo scanner, an input camera (for photographing drawings and documents), and rapid film processing equipment. The primary man-machine interacting unit is the graphic console. It contains a CRT display, graphic pencil input, alphanumeric input by keys and punched cards, special function inputs from keys, and status and program status indicators.

In addition to the hardware, there is a basic input and output software capability. Program control of the hardware is provided by the NOMAD and MAYBE programming languages. While these languages allow control of the hardware, they give little assistance in meeting the data format requirements. Therefore, a general-purpose input/output software system has been developed. It includes numeric-to-BCD (binary coded alphanumeric information) conversion routines, BCD to vector and character generation routines, symbol display and recording routines, and basic film tran operation codes, all of which allow the programmer to operate all of the hardware devices without having to understand their intricacies.

Thus, the combination of the DAC–1 hardware, the NOMAD and MAYBE programming languages, and the general-purpose input/output software provides a powerful tool for the designer. At the console he can experiment, for example, with different sizes and shapes of parts that comprise a mechanical unit he is designing (figs. 27, 28, 29, and 30). Whereas working closely with a draftsman might involve hours or days of turnaround time, he may see, with the DAC–1 system, the results of his design decision immediately and make adjustments accordingly. For example, lines are straightened, curves are drawn, the relationship of parts is shown, and various questions are answered ("Where can part *B* be located if part *A* is made larger?" and "Can part *A* be assembled with part *C*?"). Thus, many design problems can be solved immediately rather than deferred, and a permanent record of the design can be filed until needed.

This is only one example of a design automation system using a display console. Many more such developments have taken place.

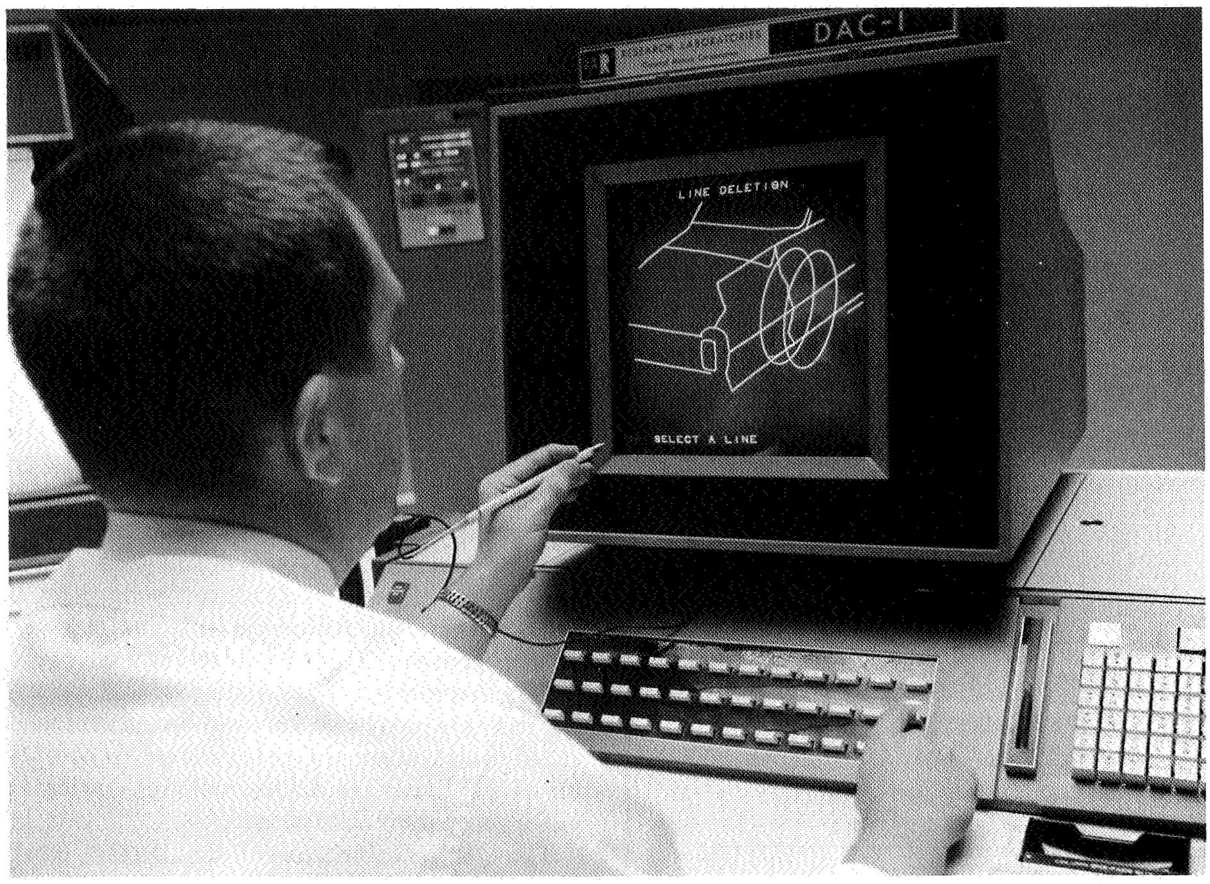

FIGURE 27.—Man-machine communication. General Motors Research Laboratories GM DAC-1 system. A research engineer checks out a computer program that allows him to modify a design drawing. A touch of the electric pencil to the tube face signals the computer to begin an assigned task, in this case "Line Deletion," where indicated. The man may also instruct the computer using the keyboard at right, the card reader below the keyboard, or the program control buttons below the screen. Hundreds of special computer programs are needed to carry out these studies in man-machine communications.

FILE MANIPULATION INTERACTIVE DISPLAY SYSTEMS

The application of file manipulation display systems to the growing needs of both government and industry promises much more extensive, timely, and flexible utilization of information stored in files. These systems are designed to grant executives, managers, administrators, project engineers easier access to the management information they use in the course of their work and to allow them to maniplate this information. The modus operandi of the interactive system to be discussed in these paragraphs is one in which the user need not be aware of the programming intricacies of the computer system he is using but yet may take advantage of its high storage capacity, fast storage access time, and computing power. This type of system falls into a category of industrial systems which will be important in the future.

The hardware and general-purpose software used for file manipulation display systems are not necessarily specialized for this particular purpose. The equipment and techniques are similar to those used for scientific and engineer-

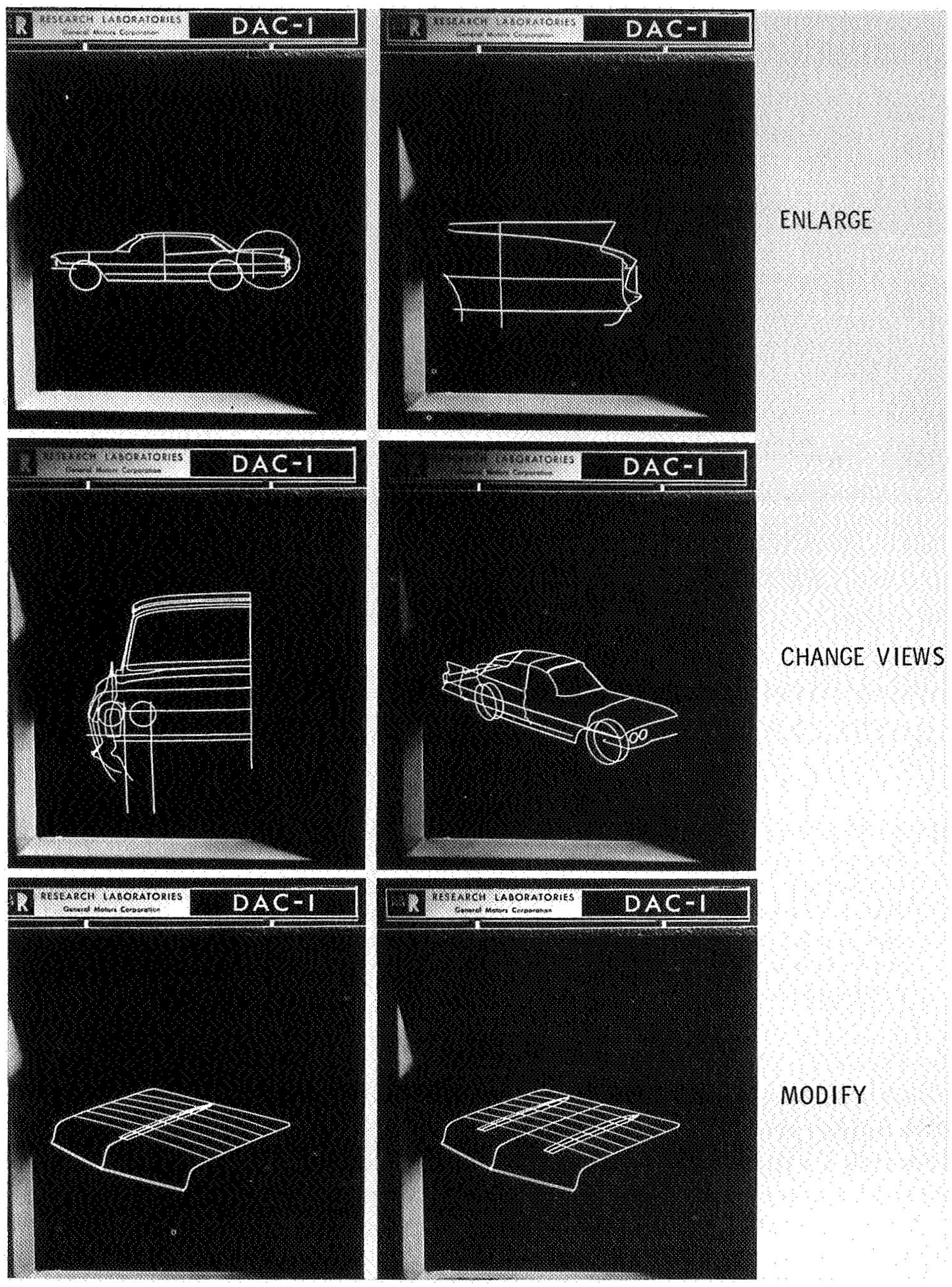

FIGURE 28.—A new angle to car design. These "before" and "after" displays were generated by a digital computer. They illustrate three of the capabilities of DAC–1, an experimental man-computer design system developed by General Research Laboratories. The drawings appear on the viewing screen of the designer's console and come from a mathematical representation of the design stored in the computer's memory. In one case, "Modify," the DAC–1 system has enabled the designer to make a major revision in the deck lid of a car while working at his console and to see immediately the results of his changes.

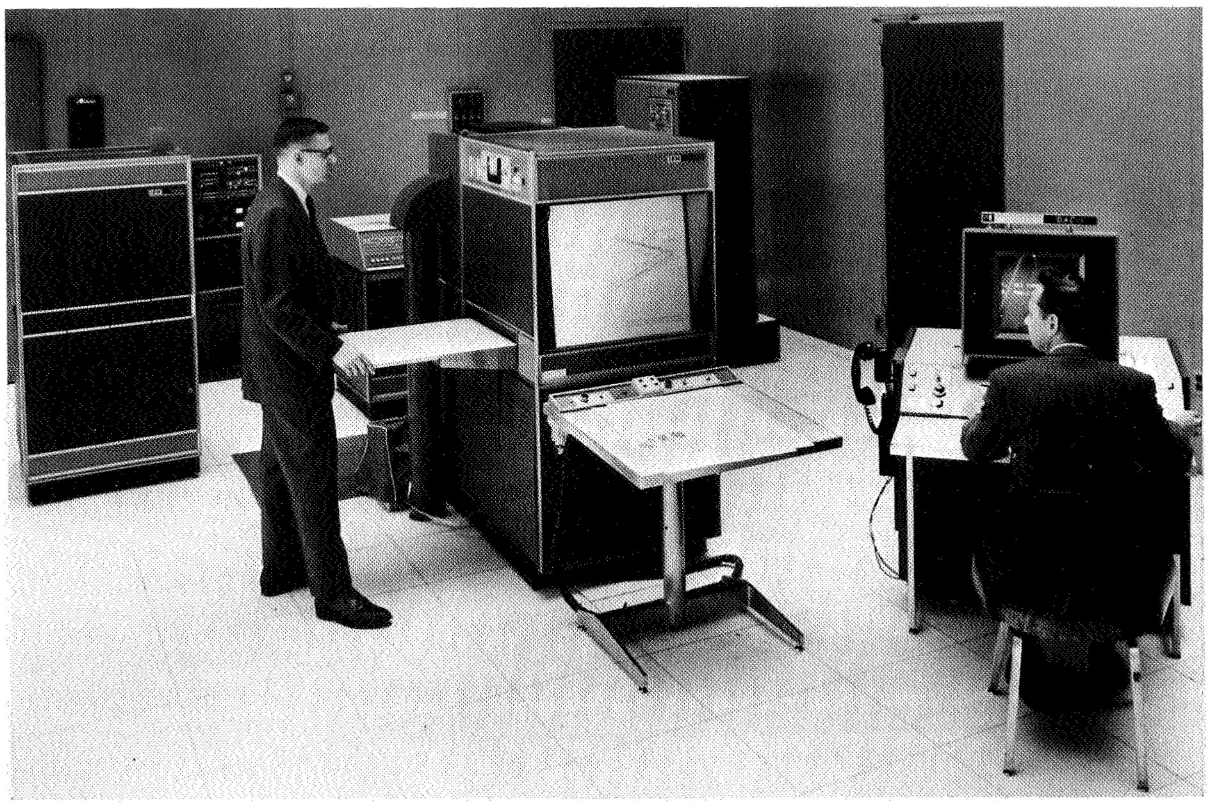

FIGURE 29.—Computer laboratory for the automotive designer. Sketches and drawings of new model cars are processed at electronic speeds. The new laboratory was developed by computer specialists at General Motors Research Laboratories, Warren, Mich. The DAC–1 laboratory features (left) an image processor for converting paper drawings into digital, computer digestible images, or, conversely, for converting images into paper drawings. At right is the graphic console where the designer can immediately review, develop, and modify his latest design work.

ing interactive display systems, and much of the Stanford Research Institute work cited below is applicable to all types of interactive systems. At present, display consoles based on the cathode-ray tube are the most prevalent (fig. 31).

The computer programming forms the most significant part of file-manipulation display systems. These programs must perform a number of functions that are extremely intricate and thus require the latest programming development. Some of these programs are:

(1) Overall control (executive)
(2) File data storage and retrieval
(3) File access
(4) Data formatting and display
(5) Input devices control.

The work at Stanford Research Institute is at the forefront of development of interactive display systems.* A significant portion of this work is being carried out under contract to NASA's Langley Research Center. The SRI-developed On-Line File Manipulation and Display System at Langley Research Center is a pertinent example of an experimental file management system. The hardware at Langley includes a CDC 3100 computer and a CDC 250 Display Console with some special devices.

The programs are for the most part contained

* Pertinent work by SRI is discussed in a number of internal documents of Stanford Research Institute, Menlo Park, Calif. See File Management Bibliography.

FIGURE 30.—Computer drawing projected from film. The drawing on the screen of the image processor (background) has come from a mathematical model—series of equations—stored in the memory of a large electronic digital computer. A GM-developed computer program records the drawing directly on 35mm film and, within 30 seconds, the developed film is projected on the view screen. Enlarged drawings can be made from the film after it is removed from the unit of GM's DAC–1 research project.

FIGURE 31.—Interactive display system console. The cathode-ray tube display console shown above is used in an on-line manipulation and display system. This view shows the CRT face for outputs to the user and three devices for inputs from the user. On the left is a special-purpose keyboard; in the center is a typewriter keyboard; and on the right is a device for locating positions on the screen called the SRI MOUSE.

in three software packages: (1) display-handling software, (2) a general file-handling program, and (3) an interpretive decision-tree compiler and executive for specifying executive functions in on-line systems.

The resulting capabilities of the system allow access to data files and permit structuring of the information to maximize visualization and understanding of its implications. Typical displays are shown in figures 32, 33, 34, and 35.

The display-handling software incorporates two levels of programs: the first, a high-level, user-oriented program called DSP, and the second, a program that performs the basic operations necessary in generating the primitive code for specific display equipment called BITFID for the more or less descriptive function "Bit Fiddler."

DSP is designed to allow programmers using it to program the system in terms of the data

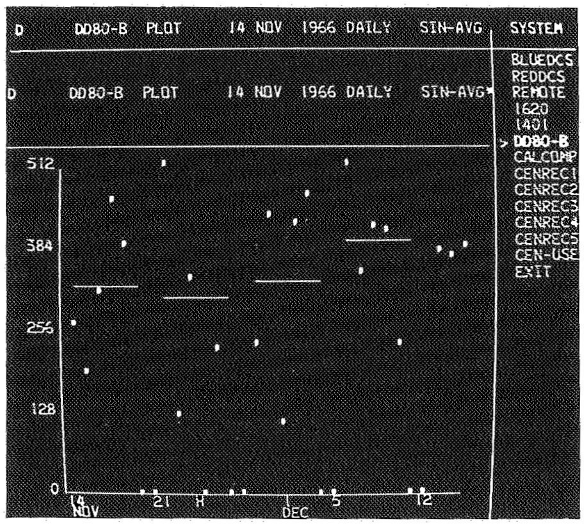

FIGURE 32.—Management information graph display. User has called for a display of the number of 35mm copies (PLOT) in a DD80–B system, shown by spots plotted against days (starting on November 14, 1966). Horizontal bars indicate weekly averages. The communciation buffer (top line on display) shows parameters of graph as they are selected from line buttons (on right) using the "mouse" prior to execution. The identical line in the label area (from below communication buffer) provides the title for the graph after execution.

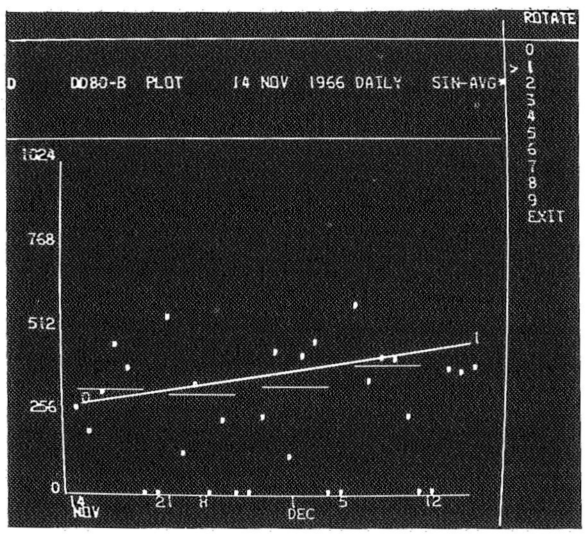

FIGURE 33.—Scaled-down graph display. Same as figure 32 except that graph has been scaled down and trendline manipulations are shown.

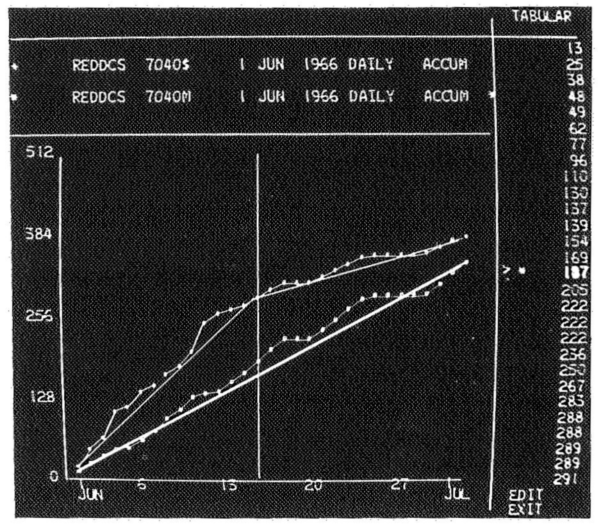

FIGURE 34.—Accumulative graph display. Accumulative graphs are shown for the hourly usage and related costs of a Red 7040 computer. The axis labels, tabular values (at right), and intensified trendline are associated with the active curve (whose label is marked with an asterisk). Note that the upper cost curve shows a break corresponding to the rate change at 176 hours.

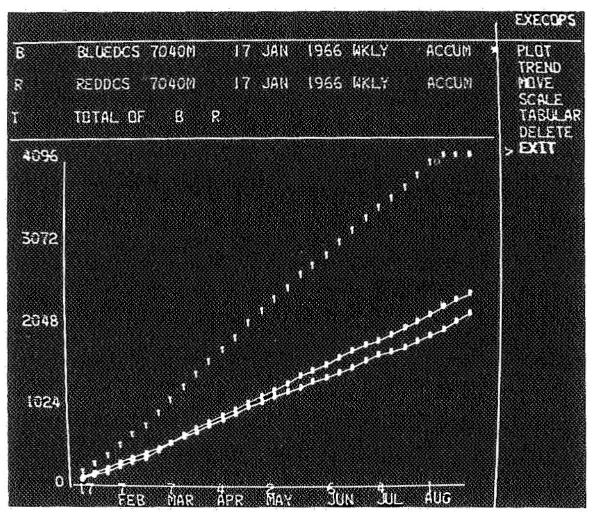

FIGURE 35.—Aggregate totals display. Three graphs are superimposed on the display. The bottom two show the accumulative weekly data for a Blue and a Red computer through direct coupled system meters, respectively. The graph labeled "TOTAL OF B&R" shows the aggregate values of the other two curves until the total exceeds the applicable data range.

they want to work with, without having to consider the physical constraints of the display equipment. It allows manipulation of named display segments and performs the necessary housekeeping functions involved in the input/output channels and peripheral devices associated with the display. BITFID performs the operations necessary to generate the basic codes recognized by a specific display system such as mode-control (typewriter mode, line generation mode, etc.) and positioning information.

The general file-handling program incorporates the concept of virtually infinite core storage (information memory) through the use of so-called PUTGET file handling routines (for "putting" and "getting" information segments). Magnetic-disc storage is used presently for auxiliary storage for interpretive programs and data, but, with appropriate extension, PUTGET can handle any computer storage medium. PUTGET allows a programmer to write his programs for the display system so that they refer to a data item by file name and index value, thus freeing him from considerations of where the data is located physically.

The interpretive decision-tree executive couples the decisions of the system user to the programs and data stored within the system. Thus, the user need not be aware of the details of the program and data storage. This program is the final and most significant step in freeing the display user of the details of the display hardware and software. The hierarchy of decisions available to the user can be characterized as a tree structure with decision nodes at various levels. Presently, a "light-button" mechanism implements presentations of possible selections. The active node of a decision-tree structure, with its list of user options, is displayed on the right-hand side of the screen. The user indicates his choice of action by means of a positioning device called the "mouse" and the program takes appropriate action based on this choice. The particular implementation of the interpretive decision-tree compiler and executive provides great flexibility in changing the data set, and the decision-tree structure can be changed radically without disrupting or causing significant changes in the action that occurs at each decision node.

EDUCATIONAL DISPLAY SYSTEMS

There has been an increasing amount of work in the field of computer-aided education, sometimes called computer-aided instruction (CAI). The overall goals are evident: to increase the number of people contributing to society at an intellectually and emotionally satisfying level. The use of computers in education has been directed toward individualized instruction in all grade levels.

Costs have, up to this time, prohibited individualized instruction for many students. The individual needs of each child continue to plague educational systems. The use of computers is not yet well understood, but new techniques may reduce the cost of individualized instruction.

Computer systems can be used as educational tools in drill and practice systems, tutorial systems, dialogue or inquiry systems, simulations, and educational research. For individualized instruction, a terminal is connected to a computer for the student. One computer can service a number of terminals. Each terminal may consist of output devices such as the cathode-ray tube and audio devices, and input devices such as the keyboard and light pen.

Drill and practice systems are largely complementary to the regular curriculum taught by the teacher. They can take a heavy burden off the teacher when individuals simply must repetitively and precisely cover examples of the subject being taught. In the tutorial system, each student is guided through a number of topics. The system provides branching according to the reaction of the student in the learning process. This branching may be either voluntary or involuntary. The student is presented with a number of facts and examples and then is asked questions about them. Guided by his answers the system branches according to the difficulty or ease that the student has with the subject matter. In the dialogue or inquiry systems, there is a true conversation between the student and the system. The system presents general problems to the student, who must then request and organize various information from the computer to solve the problems. In the tutorial system the student may be asked questions to gauge his thinking, but the student can also ask questions of the system to round out his knowledge.

An example of an experimental educational system is the teaching system called PLATO (Programmed Logic for Automatic Teaching Operation). This work has been going on at the Coordinated Science Laboratory at the University of Illinois.*

The PLATO system is applicable to all CAI techniques. Three models of PLATO have been evolved. The first uses the ILLIAC computer and a single student station. The second uses an ILLIAC and then a CDC 1604 computer with multiple student use; and the third and current model has a CDC 1604 computer with 20 student stations. The computer provides a central control and is shared by the terminals for the teaching at each station. A shared central computer such as this reduces the cost per terminal. Furthermore, low-cost terminals are possible, with each terminal independently proceeding according to the student using it. Studies have shown that up to 1000 students could use the presently configured PLATO system simultaneously, and a new system under development will handle 4000 students simultaneously.

Figure 36 shows a diagram of a student terminal on PLATO. The student can enter his answers or other information by means of a keyset connected directly to the computer. Output information from the computer is shown to the

* This work was supported in part by the Joint Services Electronics Program (U.S. Army, U.S. Navy, and U.S. Air Force) under Contract No. DA-28043-AMC-00073(E); and in part by the Advanced Research Project Agency through the Office of Naval Research under Contract No. Nonr-35-(08); and in part by the United States Office of Education under Contract No. OE-66-10-184. Current research is now an effort of the newly-formed Computer-based Educational Research Laboratory (CERL), U. of Ill.

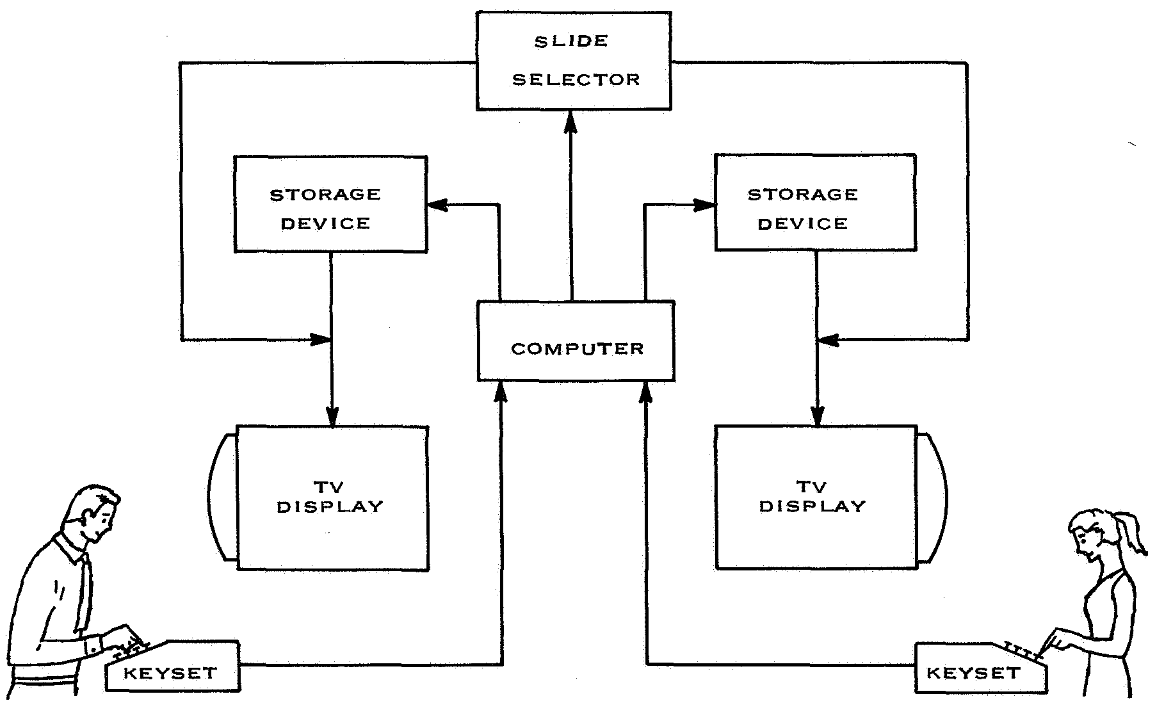

FIGURE 36.—PLATO teaching system block diagram. Shared and individual parts of the system are shown. Two or more students may share information directly from the electronic book (slide selector) or from the computer. The reactions to this information are, however, individualized for each student.

student on a TV display monitor. Two kinds of data can be displayed, one from a storage device called the electronic blackboard, the other from a slide selection device called the electronic book. The storage device provides conversion from computer coded data to images in the form of diagrams, symbols, and words. These images are plotted in a point-by-point fashion and then displayed to the students on cathode-ray tubes by ordinary commercial TV techniques. The slide selector consists of a pre-stored group of 122 frames that is constantly scanned by a TV image formation device. Any one of the 122 slides or frames can be selected for display on the student's cathode-ray tube. In both of the display sources for the student, the system converts the images to be shown into video signals finally presenting the two images superimposed on one another. Information for a student can appear on his television screen from either the blackboard or the book or from both simultaneously (fig. 37).

FIGURE 37.—A PLATO student terminal device. The student sees information on a TV-screen (which is an ordinary 525-line TV monitor), and he enters information by means of a teletypewriter keyboard, similar to an ordinary typewriter.

Development of the PLATO system and related systems is continuing at the University of Illinois. With regard to hardware, for example, development of the Plasma Display in plasma discharge cells is underway. Images are formed from many elements. Each element is a cell of gas that can be illuminated or extinguished by electrical impulses controlled by a computer. (Plasma discharge cells are described in more detail in chapter II.) With regard to software, a number of teaching programs have been written in categories mentioned above.

Tutorial programs include geometry demonstration lessons, fraction demonstration lessons, three lessons on the introduction to automatic digital computing, seven lessons on the introduction to computer programming, recursive definition lessons for high-school students, test development and studies of quantitative aptitude for higher education students. The programs also use a tutorial type of teaching logic that permits a variety of manipulation of PLATO material, including on-line editing, and that has been used to give courses in library use, computer programming, and circuit analysis.

With regard to dialogue or inquiry teaching programs, there is a lesson on scientific inquiry, a lesson on the composition of mathematical proofs, a lesson for student nurses on coronary patient care, an exercise in numerical pattern recognition, a demonstration lesson on volume or weight measurements, an experimental type lesson on teaching the alphabet, an elementary science lesson, a lesson to demonstrate PLATO lessons on circuit analysis, and drill and practice programs in arithmetic and foreign language. Combination inquiry and tutorial logics have also been developed and used to teach maternity nursing and genetics. Simulation techniques are used for laboratory type exercises in genetics and physics and for political science materials. In addition to these, there have been a number of educational research programs ranging from demonstration programs to a latency time measurement experiment on different individuals.

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CHAPTER VI

On-Line Information Storage and Retrieval Display Systems

In on-line systems there is the same relationship between human being and equipment that there is in the interactive systems described in chapter V, but there also are many other independent inputs. An on-line system may represent a continually changing state; the human being interrogates the equipment to learn of the state at the instant of inquiry and quite likely may later enter other information to alter the state yet again.

RESERVATION SYSTEMS

The main part of airlines reservation systems is behind the agent sets; that is, the communications system, central processor and storage devices. Information storage and retrieval at a rapid rate must be provided for the data concerning every flight for some time to come (usually 1 year). A number of airline reservation systems were installed in the late 1950's and early 1960's. These include systems built by IBM (SABRE for American and Delta, and PANAMAC for Pan American); Teleregister, now a division of Bunker-Ramo, (RESERVISER for Braniff and Northeast, Teleregister for National, Teleflight for TWA, Instamatic for United and Resetron for Western); and UNIVAC (490 Real Time for Eastern and File Computer for Northwest). These systems were constructed in various sizes. Many of them have undergone changes, revisions, and expansion since they were first installed and some are being replaced with newer, larger systems with additional capabilities. Two of the newest systems being built at the moment are one by Burroughs for TWA and one by Univac for United. Both of these systems will use alphanumeric cathode-ray input/output terminals (fig. 38). The central processing centers for the larger systems are quite complex and contain a significant amount of standby equipment in case of failure. Figure 39 is an example of a large-scale duplexed, high storage-capacity, data processing center. Disc files store the reservation information. These files are controlled by a dual set of control units. Redundant data channels connect the disc files to redundant central storage and input/output control units and central processing units. Note that even the power supplies are duplexed. The same is true for the input and output to the communication lines that feed messages to and from the center. Magnetic tape units are used in the system for high storage capacity where rapid access is not required.

The earliest airline reservation systems used agent sets (the name given these terminal devices) highly specialized for the purpose. In a typical agent set, a card is used for the flight or flights in question, selected from an inventory of flight cards. The card typically has coded holes and is inserted in the agent set to designate

FIGURE 38.—Airline reservation system display console. Agent set for Burroughs airline reservation system built for TWA. This newer airline reservation system uses CRT displays for rapid display of information to the agent in response to his requests for reservation status of given flights.

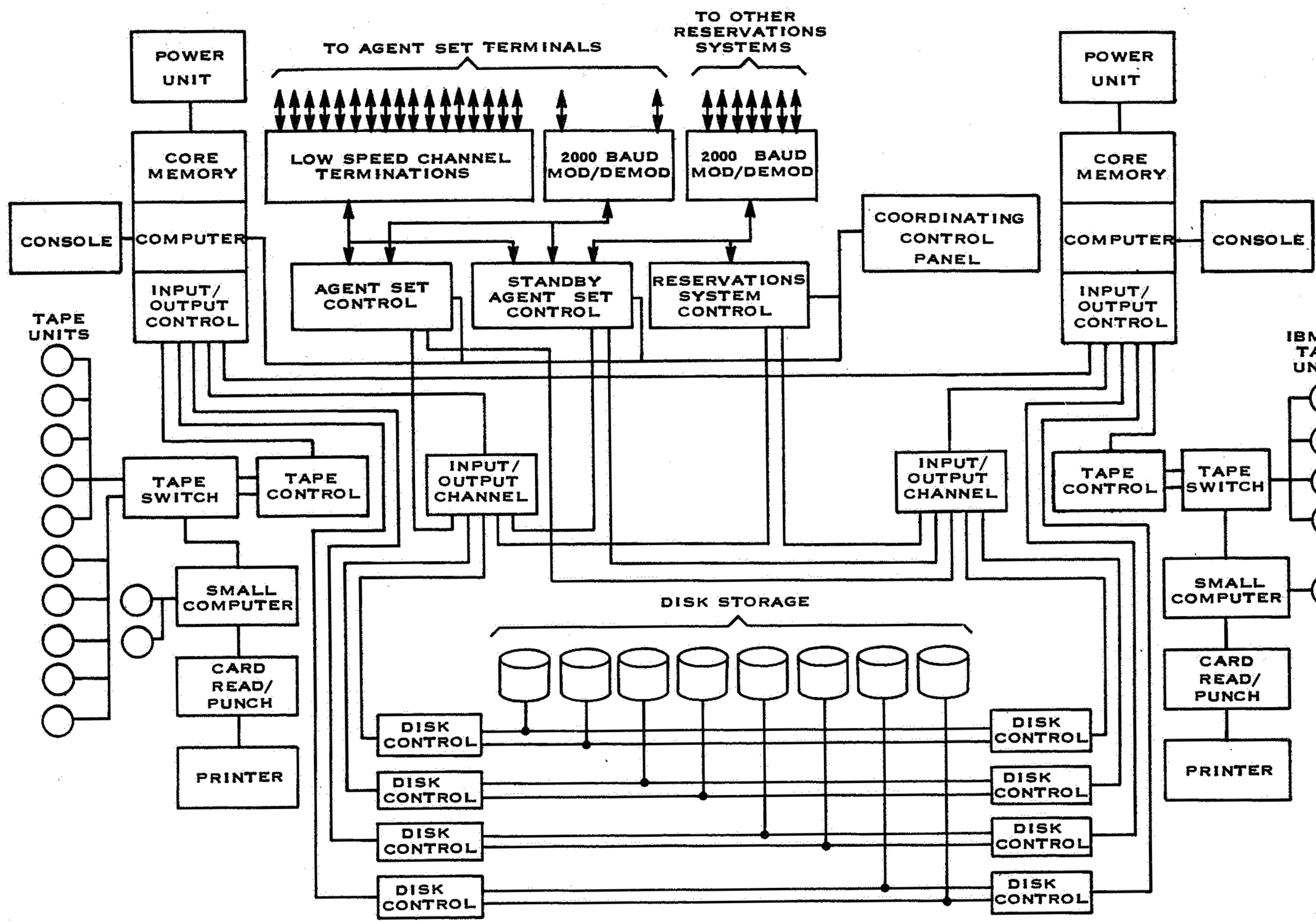

FIGURE 39.—Typical airline reservation system data processing center. (This drawing is patterned after the PANAMAC data processing center built for Pan American by IBM.) Communication control units send messages directly into the center; high-speed central computers process the information; and magnetic disc files provide storage. The interrelationship of these elements is illustrated in this diagram. The computer is linked to a worldwide communications network. Control of message flow and computer response to messages when they are received is provided by special control units.

the given flight(s). In addition, the agent may push buttons to indicate more specific information such as class. Thus, a request is made for the reservation status of the given flight. Answers to the requests are displayed to the agent either in lights or are typewritten or both. The agent then can key in detailed information regarding the reservation for the customer, for which either a standard keyboard or special keys or both may be provided. In later systems, these functions are provided by a small cathode-ray tube input/output terminal. These terminals are similar to alphanumeric cathode-ray tube display terminals which are coming into use in vastly growing numbers.*

INFORMATION ACCESS SYSTEM

Another example of an on-line information storage and retrieval system is one presently operated by the Chicago Police Department. The goal is to retrieve data on crimes quickly enough to answer questions directly from the field. If a policeman has sighted a suspect, he should be able to call headquarters and get descriptions even while the suspect is either still in view or under temporary apprehension.

To implement this system of query and response, the Chicago Police Department installed a basic computing system in 1962. Initially, typewriter keyboards were connected on-line with the computer. The typewriters were operated by dispatchers in the headquarters building. The policemen called the dispatchers by phone with their queries. Being on-line, the typewriters had to share computer service: each inquiry tied up the entire system until fulfilled. Even the answer took time for typing; if the information desired was "down the page," still more time passed before reaching it.

In 1967 the system was changed by adding 14 visual display devices with individual keyboards. Each display device is manned by a dispatcher. Furthermore, the keyboards are off-line so that a dispatcher can type in his query at his own rate. Then, by operating a *send button*, the query is entered into the computer. The response appears on the face of a cathode-ray tube. With the visual display it means the dispatcher can view an entire page at one time and select from that page, wherever it may happen to be placed, such information as is required to answer the original query.

One estimate places the improvement in response time at 200 percent. This improvement mainly stems from the advantage of the visual display device over the computer-driven typewriter and from the off-line connections for the input typewriters.

*Most of the major computer manufacturers, as well as others such as Bunker-Ramo and Stromberg-Carlson, market commercially available alphanumeric input/output display terminals.

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CHAPTER VII

Simulation Display Systems

Simulation display systems enable people to be trained in an environment more suitable for training purposes than the real environment. The high speed of computers allows them to generate images—rapidly enough to show real-time situations. In fact, a trainee can be taught in an environment where, because of the computers and displays, he sees and reacts to his surroundings as if they were real. At the same time, his reactions can be recorded and then analyzed to evaluate his performance. Other uses are made of simulation display systems also. Movies can be made for training and other educational purposes.

Within the aerospace and other related industries, the need has grown for training personnel in an environment other than the one in which the personnel will utilize this training. Two good examples are the training of airline pilots and training of spacecraft pilots. In many devices the pilot trainee sits in a cockpit mock-up and is shown a simulated view from his window and simulated instrument action. In this manner he may become familiar with the actual flight environment, without the expense and dangers of real-flight training. In the simulated cockpit, the view and indicators change in accordance with the actions taken by the pilot. To create the simulated environment, complex machinery is necessary, and special-purpose analog computers have been used for airline training simulators. Now general-purpose digital computers programmed to operate in real-time, connected to special-purpose input and output devices, are coming into use.

MANNED SPACECRAFT CENTER SIMULATION DISPLAYS

NASA utilizes training environments for astronauts which realistically simulate the actual space environment. One of the components of such systems is a display to show the astronaut the view that he might see from the window of his spacecraft. Of course, this view must reflect the relative movements of his spacecraft and show manmade and interstellar objects within view. For example, at the Manned Spacecraft Center (there are also simulation systems at other NASA sites) there is a closed-circuit TV simulation system. This system shows mock-ups or models of objects to be seen from the spacecraft. A TV camera mounted on gimbals and a movable platform is controlled from a cockpit of a simulated spacecraft and connected to a closed-circuit TV monitor. If the simulation is being used in conjunction with a lunar landing mission, for example, a mock-up of a part of the moon is in view of the TV camera. The TV monitor shows pictures to the astronaut through a special optical system connected to the simulated spacecraft cockpit. As the astronaut "moves" the spacecraft in relationship to the moon, the TV camera moves proportionately.

There are limitations in the depth of focus, field of view, and in light transmission that can be provided with such a system. Because of the physical size of the TV camera and its inertia, there are limitations in the relative motions that can be simulated. In addition, the physical size of the models or mock-up views may become prohibitively large if long duration simulated flights covering large land areas are to take place. There may be a wide range of altitudes required, changes in reflections, shadows, and other indications of movement, rapid changes in viewing angle, and many other problems. Therefore, newer methods of simulating cockpit views have been investigated.

GENERAL ELECTRIC COMPUTED DISPLAYS

One of the most promising (and at the same time, fascinating) methods now being developed for training devices is the computer-generated display simulation. The Electronics Laboratory of the General Electric Co., in Syracuse, N.Y., has developed a computer-generated simulation technique that involves: (1) storing the data describing the environment in computer memory; and (2) solving in real time the perspective equations that define the environment image on the display or image plane. All hardware for modeling and photographing in connection with the simulated display is eliminated and replaced by a computer with numerical data stored in its memory. A color TV monitor or set of monitors shows the actual display using a purely mathematical-scanning and perspective-image-computation process.

The GE-computed display system shows simulated images on 21-inch color TV monitors. The images that the viewer sees on the TV monitors are produced by a high-speed computer system developed for that purpose. The computer creates pictures of objects to be displayed from numbers stored in its memory—numbers that mathematically describe the shapes and colors of the objects. There are no TV cameras, no films or slides, and no models of drawings in the system. The viewer can see the computer's visualization from any vantage point. In effect, he enters the world of the computer by manipulating an aircraft-type control stick. The computer determines his location through the movements of the control stick, then computes and presents a TV picture of the scene as it would appear for an instant in time. This process is repeated 20 to 30 times per second, so a smooth and continuous picture is displayed, giving the operator the same visual sensations he would experience in a real-world situation.

Photographs have been made of various images produced on the system and of some of the components of the system itself. Images of NASA's lunar module and the command and service module are shown in figure 40. The viewer can "fly" around (and inside) one of the objects with respect to the other by manipulating a control stick. The computer continuously

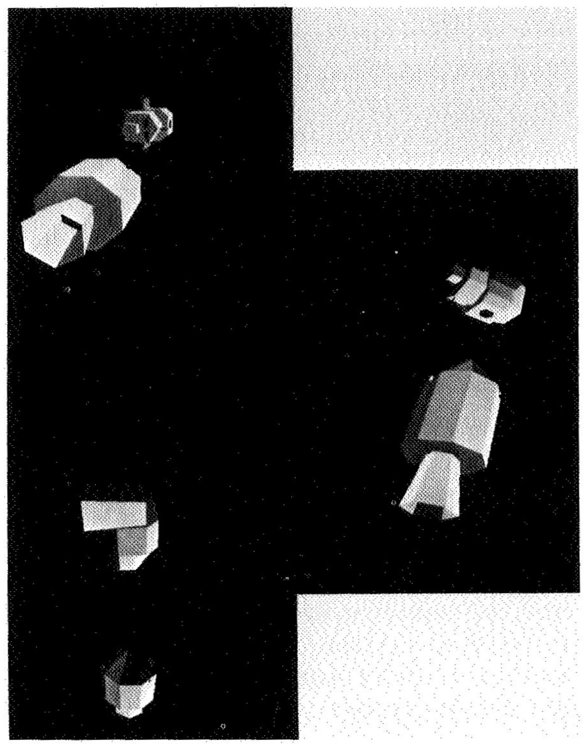

FIGURE 40.—Simulated NASA lunar module and command and service module. The viewer can "fly" around (and inside) one of the objects with respect to the other by manipulating an aircraft type control stick used for the visualization. The computer recomputes the exact perspective and size of the scene for the viewer's location.

computes the exact perspective and size of the scene for each viewer's location. The lunar and command service module simulators can be used to evaluate spacecraft control systems for rendezvous, docking, and lunar landings, in conjunction with astronaut training. Figure 41 shows how the computer visualizes an aircraft carrier of the *U.S.S. Forrestal* class. The relationship of the viewer with the aircraft carrier is produced in the same manner as in the lunar and command and service module displays. Figure 42 shows an image of an airport that the computer draws on a TV screen. The viewer manipulates the control stick to inform the computer where he would like to be in relation to the airport.

The special-purpose computer equipment built by GE contains "third-generation" hard-

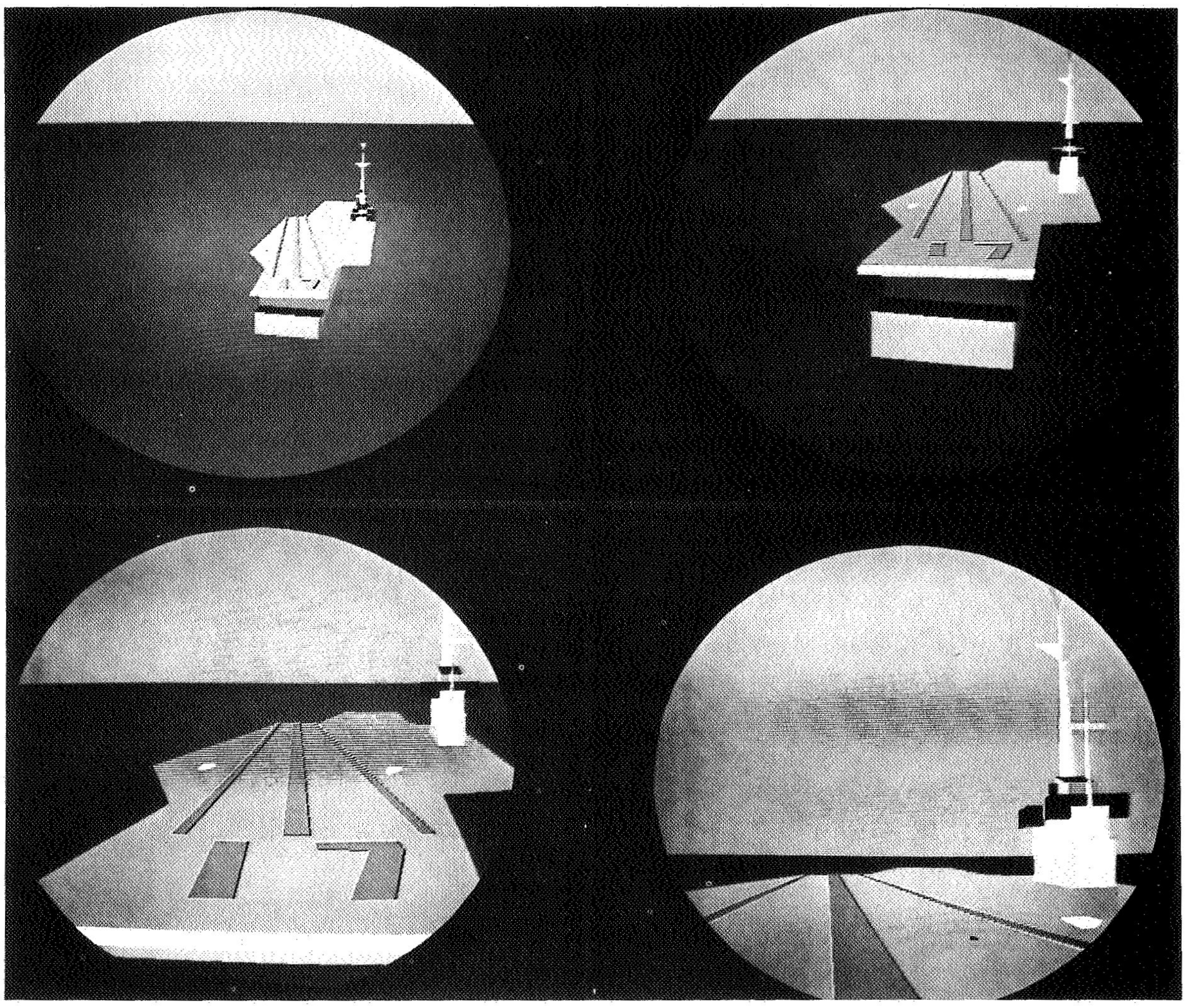

FIGURE 41.—Simulated aircraft carrier. The computer visualizes an aircraft carrier of the *U.S.S. Forrestal* class such that the relationship of the viewer with the aircraft carrier is produced in the same manner as in figure 40.

ware, that is, integrated circuits. Figure 43 shows 4 of the 12 cabinets comprising the computed display. The system includes 85 000 logic gates, 52 000 integrated circuit cans, and 587 plug-in circuit cards, 498 of which are multilayer. Figure 44 shows a close-up of one cabinet in the computer display indicating the arrangement of circuit cards. These cards plug into motherboards in the rear of the cabinet. In figure 45 is a front and rear view of two of the 498 multi-layer circuit boards in the computed display.

In general, the computed display system uses both specially developed hardware and software for the real-time simulated images that it produces. The displays are 21-inch color monitors originally built for commercial TV at 525 lines per frame. These monitors have been improved, however, to allow display of a 600 line by 600 element TV raster consisting of 360 000 elements. A large range of colors and hues is possible on each monitor. The frame rate is 20 to 30 frames per second, which means that images moving as in real time look lifelike.

The equipment that drives the display monitors consists of special-purpose digital com-

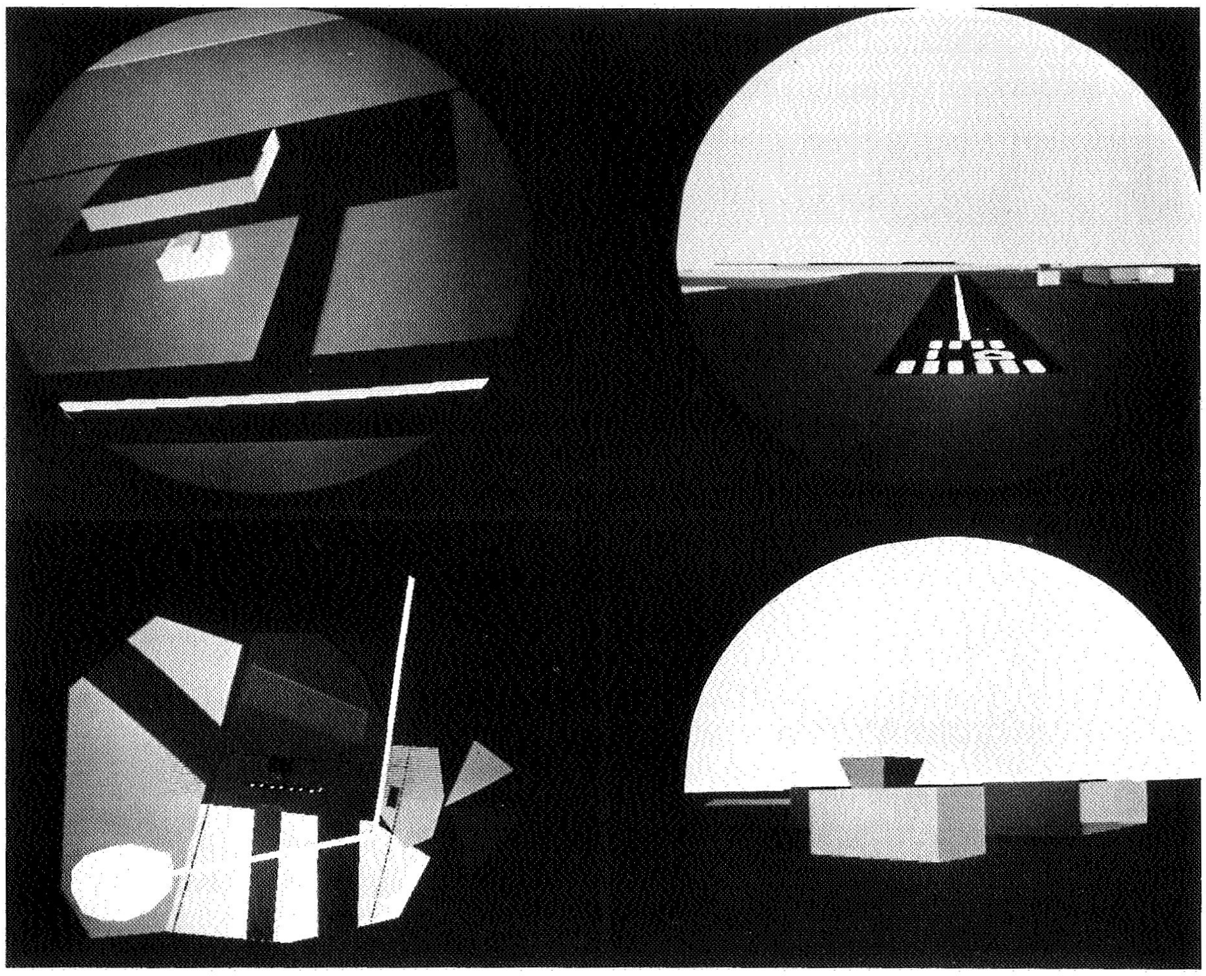

FIGURE 42.—Simulated airport. An image of an airport that the computer draws on the TV screen is shown. The viewer manipulates the aircraft-type control stick to inform the computer where he would like to be in relation to the airport, in the same manner as in figures 40 and 41.

puter units (figs. 43, 44, and 45). One unit is called the vector-calculating unit; the other, the object-generating unit. These operate with a special-purpose magnetic core memory for storing data consisting of three banks of 2000 words each (30 bits per word) with 2-microsecond access time. In addition, there are 4000 words (24 bits per word) of magnetic core memory for storing programs also with 2-microseconds access time.

Television images are created and shown on the monitors by computing fast enough to keep up with the television scanning rate. The image is not computed and stored in memory for subsequent display; the computed units are synchronized to the sweep and frame rates of the TV monitors. The objects to be shown in the image are stored as coded numbers in the memory of the computing units, which then reconstruct the images in TV form as they are being displayed. Thus, the computing units operate at about 1000 instructions per TV frame. To do the necessary operations at a high enough rate, the circuitry performs 10 million operations per second (called the clock rate).

The computing units are controlled by a modified general-purpose computer. It is a Raytheon 520 that has two banks of magnetic-core mem-

FIGURE 43.—Computed-display interface hardware. The special-purpose computer equipment built by GE contains "third generation" hardware, that is, integrated circuits. The system includes 85 000 logic gates, 52 000 integrated circuit cans, and 587 plug-in circuit cards, 498 of which are multi-layered.

ories, with 4000 words each and 2-microsecond access time, and one bank of special "biax" magnetic memory with 256 words, and 1-microsecond access time. The bit transfer rate between the 520 and the computing units is 5 MHz. Because the computations are made in real time, a decision is required once every 100 nanoseconds. The Raytheon 520 provides control for the system; it reads programs in and out of the computed display system and allows operation of the system from a central console. Three images per scene can be shown simultaneously in real time. For example, the lunar module and the command and service module shown in fig-

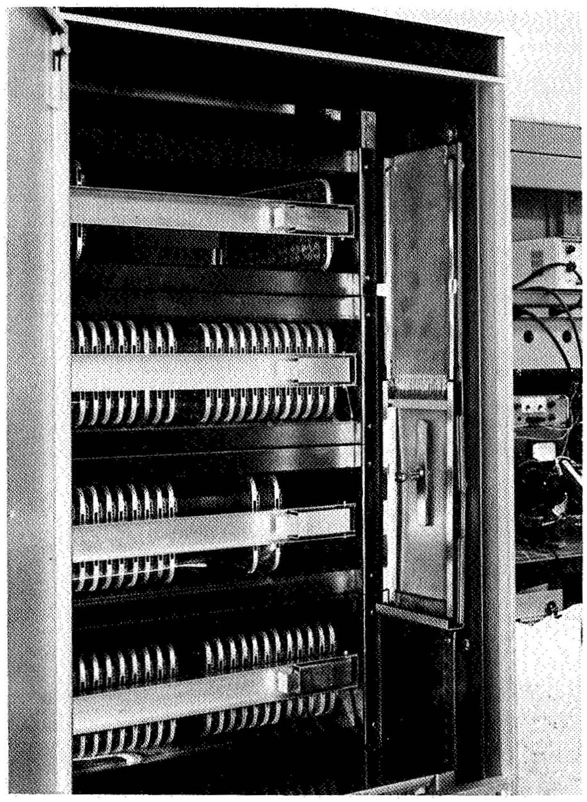

FIGURE 44.—Interface hardware closeup. A closeup of one cabinet in a computed display is illustrated above. The figure shows an arrangement of circuit cards which plug into motherboards in the rear of a cabinet of the computed display.

ure 42 can be presented as follows:

(1) The view seen from the lunar module

(2) The view seen from the command and service module

(3) A view of both objects seen from a point some distance away.

The relationship of each object with respect to the others is properly displayed in true perspective showing all motions and relative motions according to the given view.

A system with these capabilities has much utility. The computed display system has a number of advantages over other types of visual simulation. It allows the programmer to select objects, their sizes, and their colors, and "construct" them in virtually any configuration to be visualized. Then the movement and distance from an observer is computed and displayed in real time. The results are as follows:

(1) The image retains true perspective for all vehicle dynamics (fig. 46).

(2) All objects and textures in the image are in proper focus.

(3) The contrast, luminescence, and color capability are commensurate with the real-world conditions that are being simulated.

(4) The resolution and field of view of the generated image is comparable to that of the human eye.

(5) The image-generation technique does not impose undue restrictions on the ability to project the final image.

(6) The image contains all the information sources used by the pilot under the actual contact flight conditions that are being simulated.

COMPUTER-PRODUCED MOVIES

Bell Laboratories has pioneered in the development of computer-produced movies. The physical setup consists of a visual display device, a microfilm recorder and a computer. The programs in the computer control the beam of a cathode-ray tube so as to "draw" the successive frames. Each frame is photographed by the microfilm recorder.

The movies produced by this system are not of the cartoon comedy variety although this has been done elsewhere. Rather, they are either animated illustrative drawings found typically in educational films on such subjects as electricity or physics, or they are mechanical drawings in which straight lines and arcs of various curvatures are combined and perhaps repeated to create a total mechanical drawing.

The guiding program for producing movies is, necessarily, complex in proportion to the versatility granted to the resulting drawings. One language that has been developed by Bell is called BELFLIX which consists of instructions that generate straight lines (really consisting of a succession of dots) and arcs of various curvatures. In addition, there are instructions for filling in areas already outlined with specific shades of gray, for enlarging a specific area of a picture or of dissolving one picture with another. There are also positioning instructions for drawing a picture in any direction on

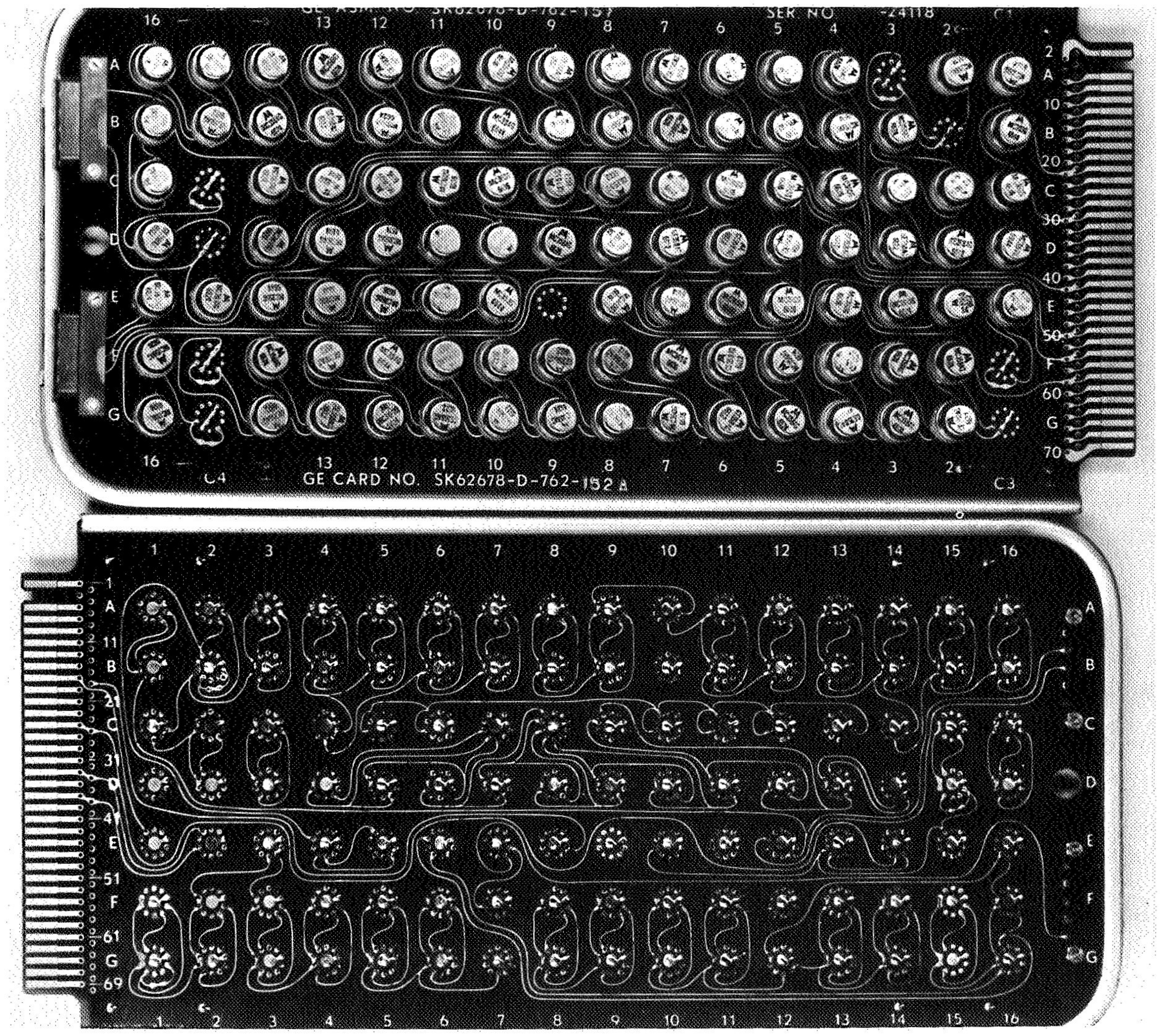

FIGURE 45.—Multi-layer circuit boards. These multi-layer circuit boards are used in the computed display system. The front and rear is shown of two of the 498 multi-layer circuit boards used in the computed display.

the display. In all, there are about 25 instructions, each carrying appropriate parameters for determining the details of a specific application for the instructions. The capabilities of the BELFLIX language do not include much that cannot be performed by hand. Its specific value lies in periodic or symmetric sections of a picture.

The chief payoff in the movie-making operation is realized on the second or later movie on the same subject. By then, the stored subroutines for special shapes and designs mean that the second movie is nearly half finished. The movie programmer has developed a more powerful language for animating the particular subject of interest.

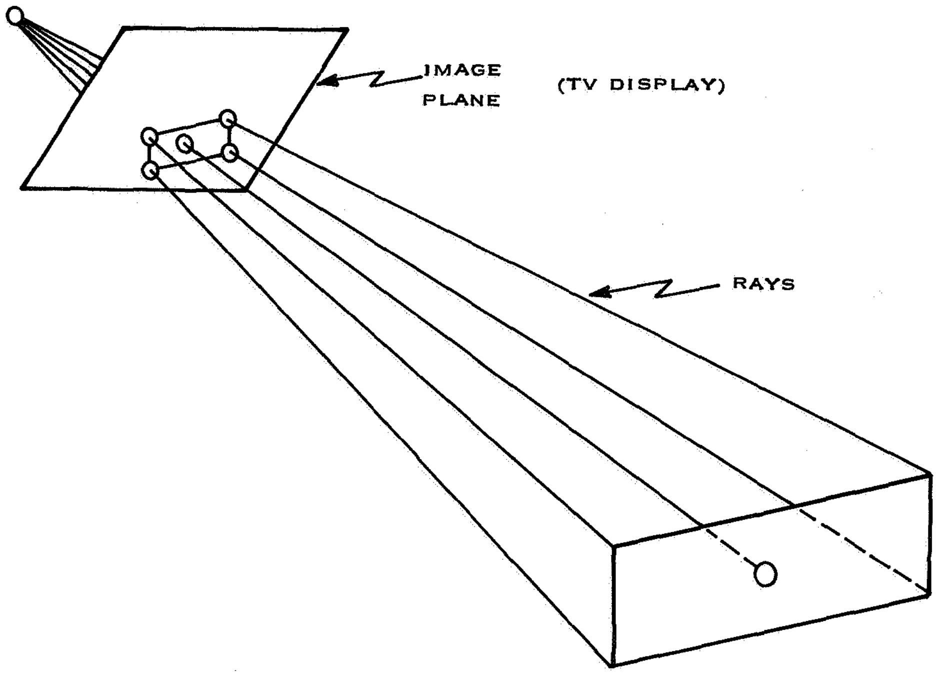

FIGURE 46.—Geometric image relationship. The computed display system always provides the proper perspective of an object being viewed on the screen regardless of the relationship between more distance from viewer to the object including real-time motion between the two. As shown, the formation of the image on a computed image plane is geometrically accurate because the image plane is formed as if rays between the object and a viewer for each point on the object intersect the image plane at precisely the proper location.

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CHAPTER VIII

Miscellaneous Display Systems

There are many unusual applications of visual display systems. Many are specializations of already discussed systems. Some, however, are sufficiently interesting to be described here.

COCKPIT DISPLAYS

As complex, sophisticated aircraft and spacecraft evolve, new problems in control arise. The control of modern aerospace vehicles, including helicopters, VTOL and STOL aircraft, SST's, and spacecraft, with such diverse mission requirements as zero-zero rugged terrain landing, low-level contour flying, hovering, high-speed intercept, and free-space rendezvous, has exceeded the performance limits of early cockput display devices. Greatly increased commercial air traffic, with resultant air terminal congestion, has generated need for dynamic and informative displays to aid the pilot. Unfortunately, off-the-shelf gauge and indicator control instruments do not adequately present all of the guidance and control information needed for the operation of modern air and space vehicles.

In attempts to overcome the problem, designers have experimented with display systems that present, in a real-world context, aircraft pitch and roll attitude, magnetic heading, air speed, ground speed, altitude, and terrain feature information. Landing information presented in a synthetic, observer-view format provides the pilot with air speed, wind velocity and direction, glide slope, approach path and runway position. TV-like screen displays of landing information are being used to test the feasibility of synthetically replacing the real-world view when it is obscured from the pilot by inclement weather. Experiments with high-contrast display units that depict aircraft subsystem operation sequence and status in a dynamic graphic format show promise for the future.

Although human response characteristics have been fundamentally important to the design of aerospace vehicle control displays, severe physical constraints imposed by air and spacecraft design have directed considerable attention to display equipment size, weight, power needs, reliability, and readability. Integrated circuitry, compact packaging, low-power requirements, and ruggedness have become common airborne display equipment features. Aircraft ambient lighting conditions and requirements for versatility in displays impose rigid performance specifications on display units. Cathode-ray tube displays generated by compact, onboard computers and presented in a "head-up" fashion have successfully demonstrated the flexibility and versatility of CRT display units. The relatively low brightness of the CRT image, however, is one of the most limiting factors in using this display device for cockpit, flight-information presentation. Much effort has been put into developing electroluminescent display devices to overcome the brightness problem, but the flexibility and resolution of present electroluminescent display units are more limited than that possible with currently available CRT devices.

An example of research sponsored to develop better methods of displaying aircraft control information is found at the NASA Ames Research Center. The objective is to conduct flight research on component and display element requirements for a zero-zero landing system. In preliminary studies, a simulation of an aircraft landing system was set up on an analog computer system. The system was "flown" in an aircraft simulator to consider types of displays that would be acceptable for zero-zero landing. (See figure 47 for a schematic drawing of the simulated system.) Test pilots concluded that it would be possible to land an actual aircraft under zero-zero visibility conditions using the display system.

Based on the results of the simulation study, recommendations and plans were made for a flying laboratory (figs. 48 and 49). The aircraft landing display system consists of two transponders placed at either side of a runway, a radio altimeter, a repackaged SDS 920 computer, an EAI analog computer, and three raster-scan CRT display consoles. Signals echoed from the two transponders, ground speed and aircraft attitude information and radio altimeter readings are integrated by the 920 to provide composite display generation commands. Based on radio altimeter signals and return signals from the two transponders, the SDS computer calculates aircraft distance, bearing, and altitude relative to the runway. The midpoint, slope, and width of the display lines are computed digitally. The 920 drives the hardwired EAI analog computer, which converts the display line parameters to display equipment driving signals. The display screen is blanked to remove retrace lines. The display is refreshed from the 920 digital-to-analog converters.

The resultant, dynamically updated display, as shown in figure 50, provides the pilot with real-world, landing-approach, glide-path information. Aircraft have been flown to touchdown using this display system.

IMAGE ENHANCEMENT, JET PROPULSION LABORATORY

As a result of recent efforts at the Jet Propulsion Laboratory to improve the quality of spacecraft-originated photographs of the Moon and Mars, the science of computerized visual image presentation has been advanced significantly. The significance for science at large lies not only in the valuable data recovered during space missions but also in the application of the image enhancement techniques to other fields.

The function of the JPL video enhancement system is to reproduce television pictures transmitted from the Ranger and Mariner spacecraft as faithfully as possible in terms of resolution, geometry, and photometry. The purpose of the video processing is to overcome limitations imposed by noise distortion and by the information bandwidth inherent in the deep-space telemetry system. The pictures are "cleaned-up" by a computer process after the images have been translated to a digital form. The corrected picture can be enhanced in contrast and used for detailed visual interpretation, or the improved digital version can be used by the computer for further interpretative and statistical analyses.

Three problems peculiar to television imaging systems and electronic data transmission systems contribute to difficulties in spacecraft photo-interpretive and map-making processes. The resolution of the television vidicon camera is limited by the scanning-beam spot size. The geometric fidelity of a vidicon scanning camera is worse than that found in film. The noise associated with the transmission system is unique to electrically encoded pictures.

Early in the Ranger project, data were digitized directly from the photographs by employing a process in which a light-beam-scan was converted to an analog signal and then to a digital signal. Much data, however, were lost in recording the photograph itself. This difficulty was overcome by recording the spacecraft signals directly on magnetic tape at the time of reception. Ground recovery losses were thus minimized by directly processing the digital data from space.

Distortion Corrections

In digitized form, discrete points on the photograph (approximately ½ million per square inch) are converted to 64 values, 0–to–64, so as to represent numerically the gray level of each point. The digitized image is read into an IBM 7094 computer where a series of corrections are made.

Geometric Distortion

The first correction process corrects for geometric distortion, that is, physically straight-

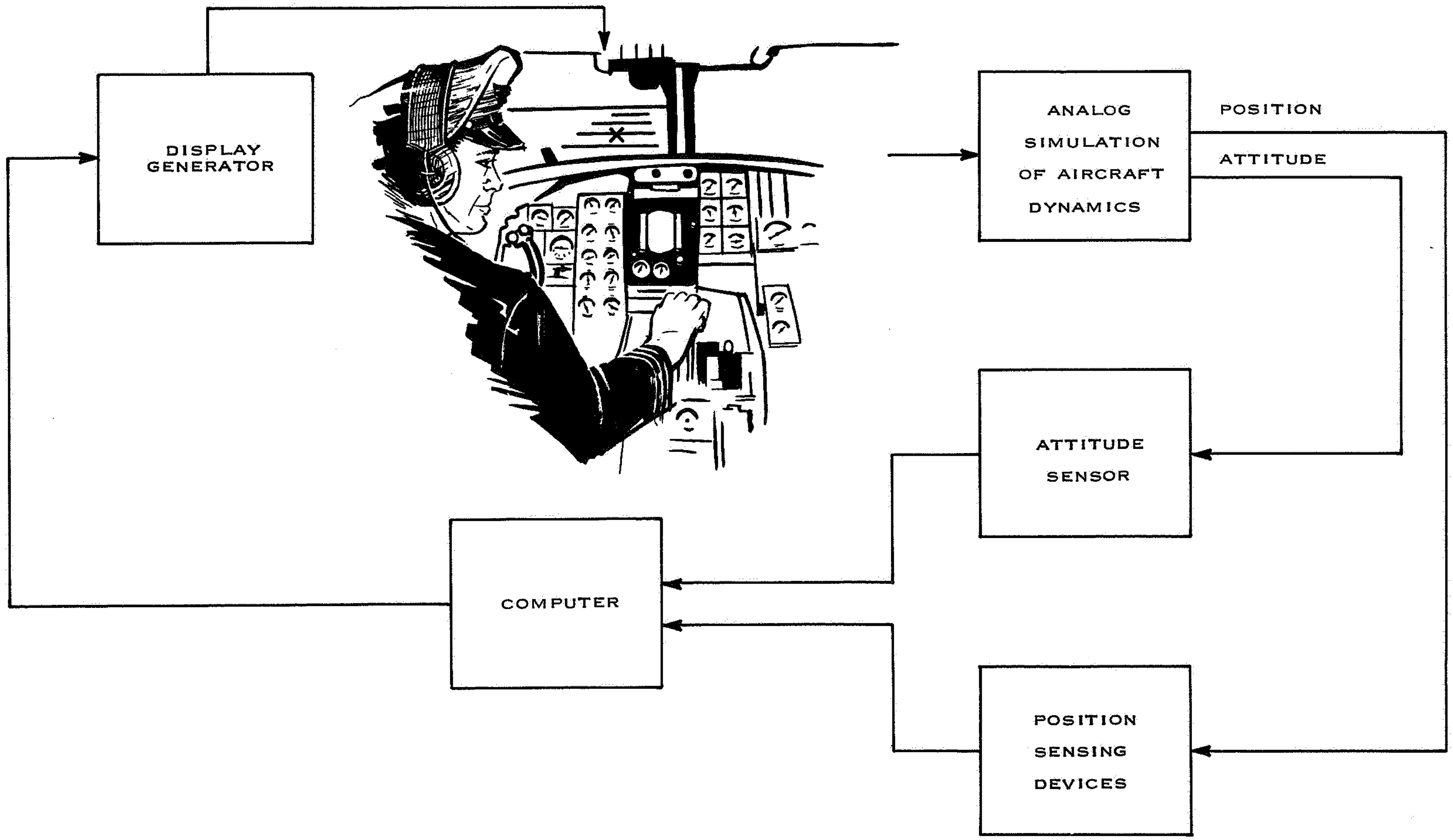


FIGURE 47.—Zero-zero landing system simulation. This drawing depicts the functional arrangement of a ground simulator used at the NASA Ames Research Center to investigate zero-zero aircraft landing display systems.

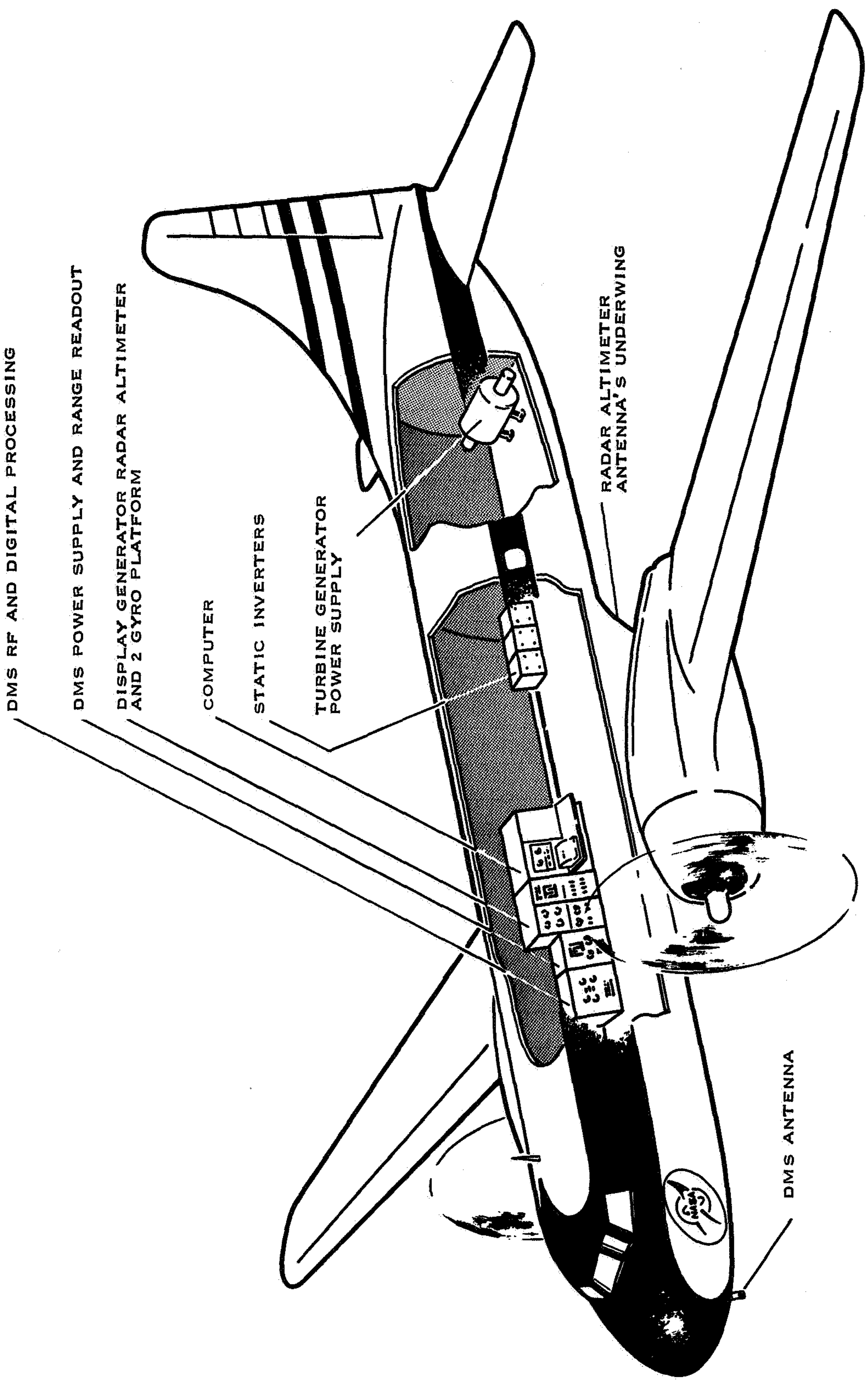


FIGURE 48.—Flying laboratory for zero-zero landing system studies. An aircraft display-system laboratory, similar to the one sketched above, was outfitted at NASA Ames Research Center, Moffett Field, California, as an experimental station for testing and developing a prototype all-weather, minimum-visibility, head-up display-landing system. Aircraft have been brought to touchdown with this system.

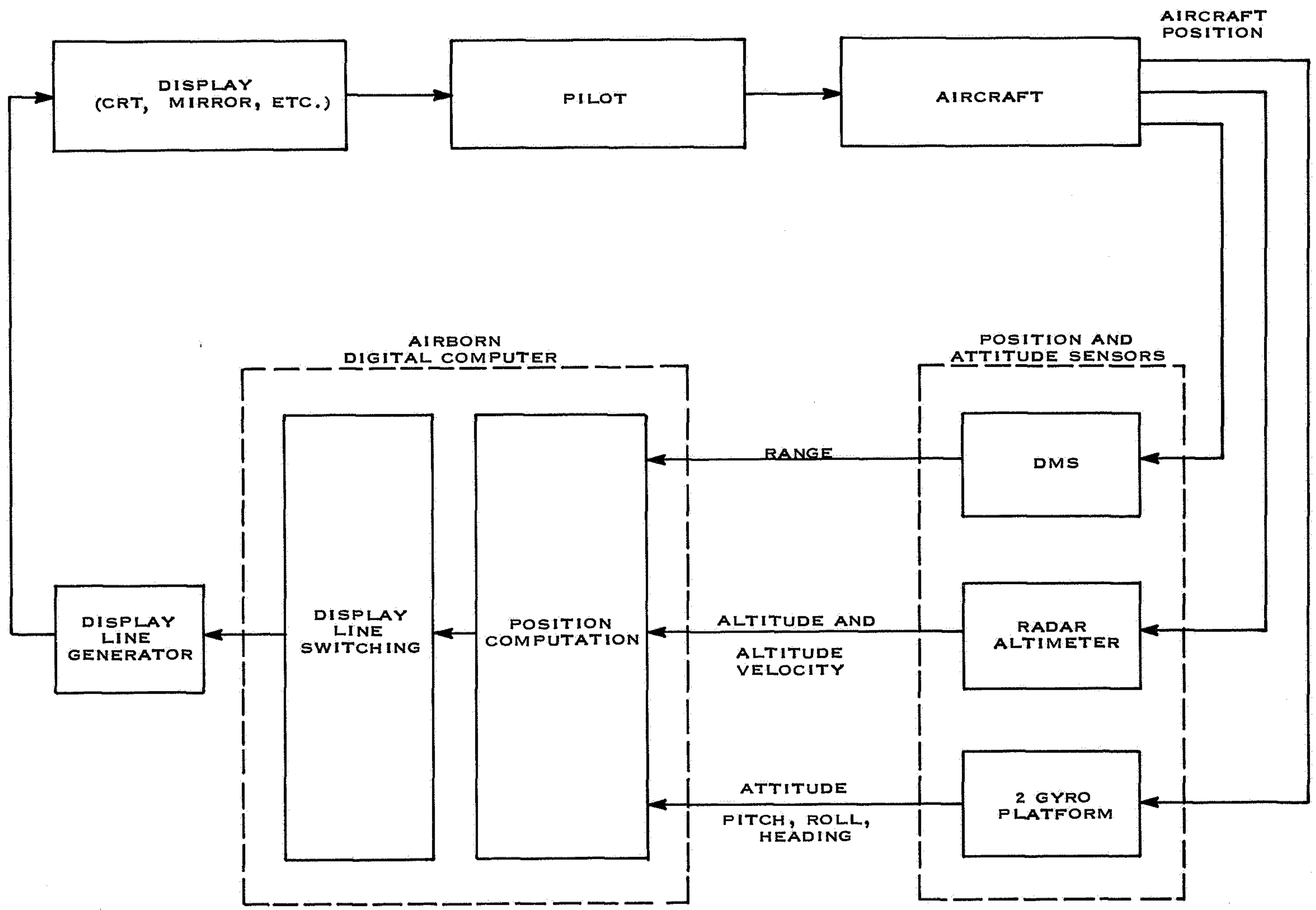


FIGURE 49.—Block diagram of zero-zero landing system. The above block diagram shows the system configuration and data flow for a prototype, minimum-visibility, airborne, landing-aid system currently being tested at NASA Ames Research Center.

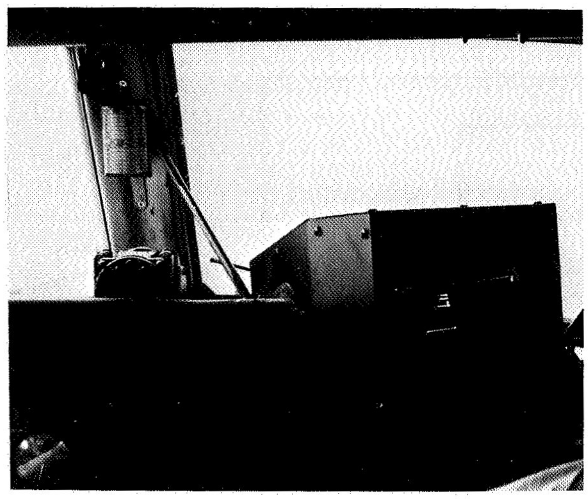


FIGURE 50.—Cockpit landing display. The above display is dynamically updated by a computer that calculates display line positional components from transponder and radio altimeter information. The top horizontal line represents the horizon; the vertical line depicts a "ghost" aircraft landing ahead of your airplane; the bottom lines represent the runway.

ens the photo image. The calibration is determined from pre-flight grid measurements as well as post-flight measurements of a superimposed grid with known vertical and horizontal coordinates. The geometrical error in the photo is corrected by distorting the grid back to its original proportions (fig. 51).

Photometric Correction

Photometric correction allows for the nonuniform brightness response of the vidicon camera. Photometric measurements are made for each scan line over the entire picture frame. The correction is performed by summing a number of frames and taking the result as an approximate gray calibration.

Random Noise Elimination

Noise present in the transmitted Ranger moon pictures is treated in two ways. Large amplitude noise elements visible in the picture as "snow" are replaced by the average of local points. Low amplitude noise is detected by superimposing picture frames with overlapping areas of view. The congruence of the photographs is established by calculating adjustments in translation, rotation, and magnification. After the pictures are matched, they are improved by averaging repeated areas. The reliability of the averaging is increased by weighting each point according to its magnification or calibration adjustments, or weighting in terms of noise measurements in the individual frame.

System Noise Removal

System-noise removal processing eliminates spurious visible frequencies superimposed on the image. The system noise, stated in terms of cycles per centimeter, is normally clustered around a single frequency. An appropriately peaked filter, similar in concept to a radio tuning filter, cleans out the noise (fig. 52).

Scan Line Noise Removal

Another type of noise is caused by the fact that all vidicon camera scan lines are not identically reproduced. Scan line noise appears as a fluctuation from line to line although within the line relative brightness is correct. This noise is eliminated by calculating the average value of the scene brightness in the vicinity of the point to be corrected. The difference between the average brightness of the scene and the average brightness of the line is taken as a correction to the point.

Resolution Improvement

One final correction process takes into account that the scene resolution is finer than the scan beam-spot of the vidicon camera. Losses in the transmitted resolution result in severely attenuated higher frequencies. A properly chosen high-frequency response filter compensates for this deficiency (fig. 53). Figure 54 shows the results of applying these photographic correction techniques to Surveyor I moon pictures.

Other Applications

While these automated photographic enhancement techniques are still in the experimental stage, tests have been conducted in the biomedical field that have proved rewarding.

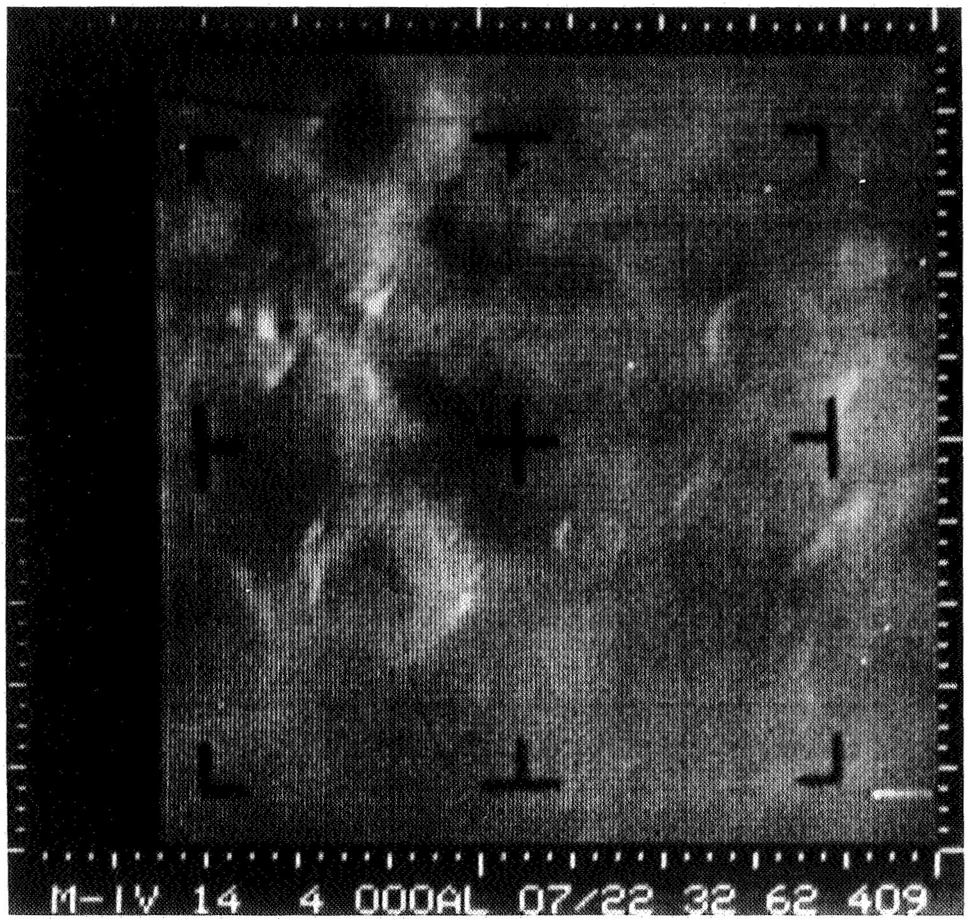


FIGURE 51.—Mariner IV Mars photograph. This photograph originated on July 14, 1965, from the Mariner IV spacecraft. The picture, taken at a slant range of 7600 miles, was transmitted back to the deep space network center at the Jet Propulsion Laboratory in Pasadena, California. At JPL, image enhancement techniques removed distortion from the photograph and thereby increased observable detail. The grid marks shown on this photograph were used to establish geometric coordinates.

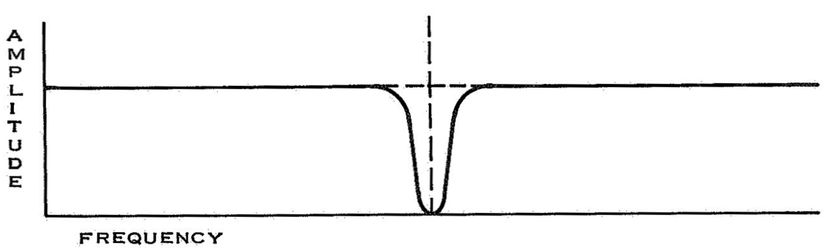


FIGURE 52.—Simple notch filter.

The possibility of improving X-ray photographs for the early diagnosis of serious human ailments has intrigued several of the nation's leading medical schools. These institutions have submitted X-rays of brain, heart, and lung areas, and photographs of eye and foot deform-

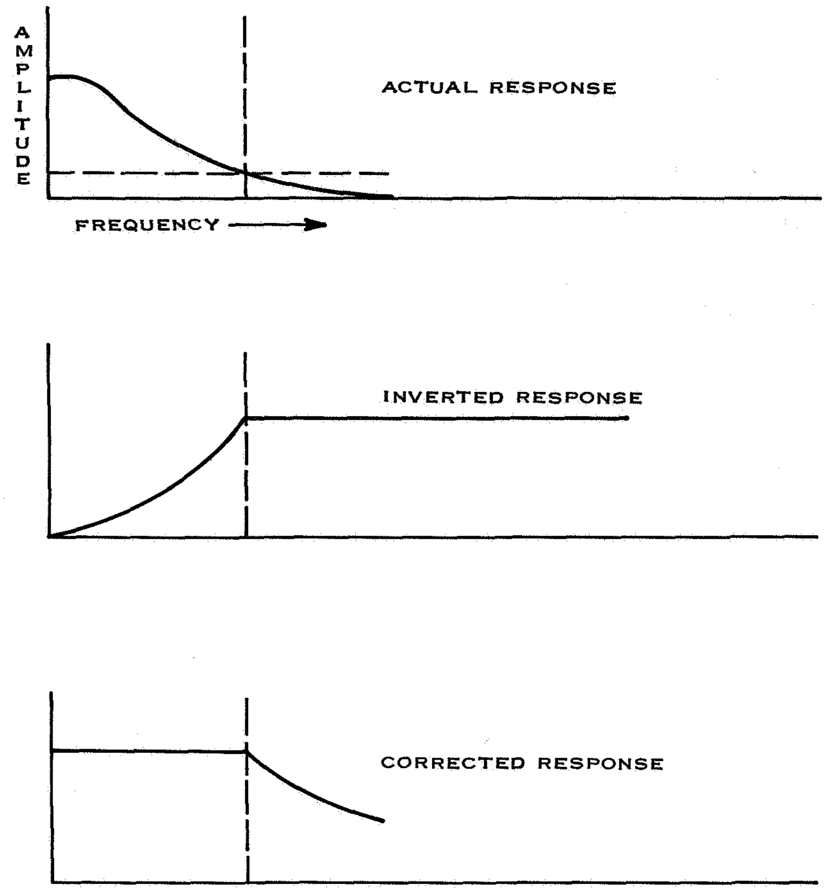


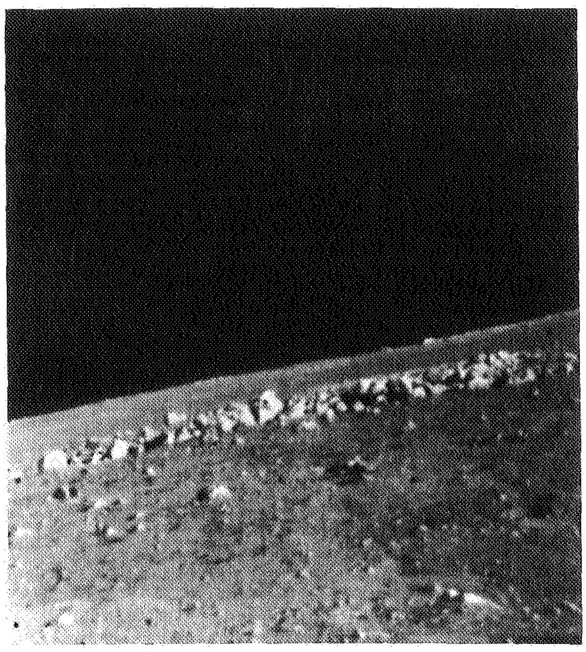
FIGURE 53.—Frequency response curves.

ities to the computerized process instigated for enhancing moon pictures. Physicians and radiologists are hopeful that the computer enhancement techniques will enable them to sharpen biomedical pictures, especially of soft tissues, and perhaps detect more readily the beginnings of cancer, heart disease, and other abnormalities (figs. 55 and 56).

Two factors are important in the automated X-ray analysis procedure: frequency enhancement and pattern extraction. Frequency filtering techniques similar to those developed for the moon-photo processing are used.

By employing the knowledge gained earlier from geometric and photometric distortion correction research, two X-rays of the same area of the body can be made congruent. Once matched, a point-by-point subtraction of corresponding gray-scale point values will extract the net change between the two X-rays. Results from a computer program that ascertains the difference between an early X-ray showing no abnormality and a later one beginning to show disease are reported to be encouraging.

Continuing research by Jet Propulsion Laboratory staff and other groups such as The National Biomedical Research Foundation, Silver Spring, Md., to develop computer techniques for analyzing bacteria, chromosomes, molecules, blood cells, and Papanicolaou (pap) smears promises the possibility of improved medical diagnostic procedures and increased understanding of the life process.



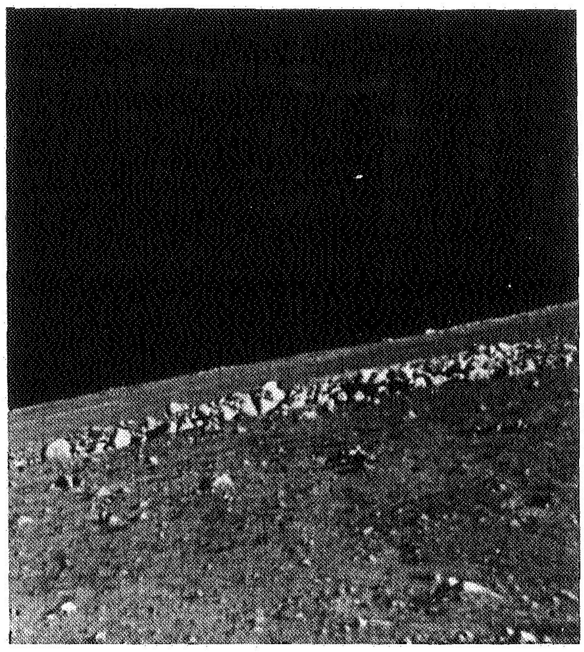


FIGURE 54.—Surveyor I Moon photograph. The picture at the right is the clarified version of the indistinct moon photograph (left) received from Surveyor I. The line of large, rounded rocks marks the near rim of an ancient moon crater several hundred yards in diameter. The crater's far rim can be seen on the horizon. The narrow-angle photograph shows the lunar surface southwest of Surveyor's landing site.

FIGURE 55.—Skull X-ray enhancement. The photograph on the left is an unprocessed X-ray of a human skull. The computer-processed photograph, as shown on the right, brought out blood vessels previously undiscernible in the highly exposed frontal portion of the skull.

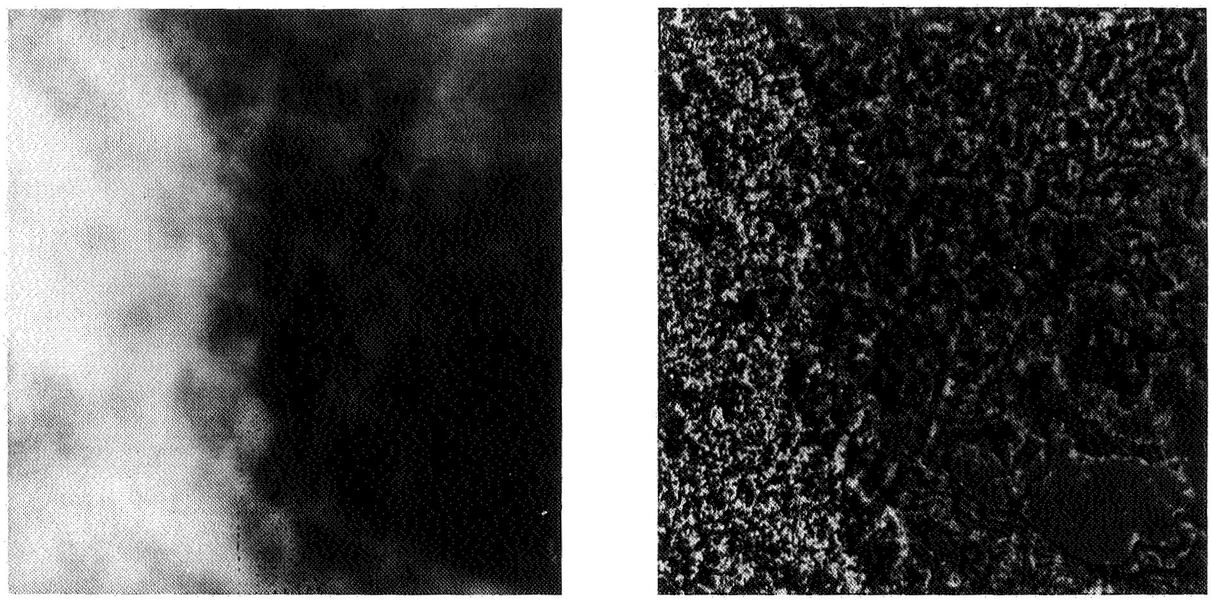


FIGURE 56.—Mastoid X-ray enhancement. Minute detail of a human mastoid structure becomes visible in the photograph on the right after application of the photo enhancement process to the enlargement of an original X-ray on the left.

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