A NEW VISUAL SIMULATION TECHNIQUE FOR PILOT TRAINING

CARL J. VORST
McDonnell Douglas Electronics Company

INTRODUCTION

Visual simulation has become a major factor in replacing aircraft hours with simulator hours for pilot training. Rapid increase in visual use, made possible by computer generated imagery (CGI) technology, is in turn a major factor in increased simulator use. Generally replacing television model and film approaches, CGI has demonstrated training flexibility and low cost when properly applied. This paper presents application of a new CGI technology particularly suited to the problem of pilot training; that technology being the heart of the VITAL system developed by McDonnell Douglas Electronics Company.

A general CGI characteristic is that equipment complexity is directly related to instantaneous scene content. Of the two general CGI categories, raster and calligraphic (stroke written) scan, both require similar size data base storage and processing capability. An important difference is that raster scan requires a significant amount of parallel processing while calligraphic processing is serial. This translates to the potential for considerable hardware savings with calligraphic use.

Consideration of visual requirements demonstrates that overall instantaneous scene complexity is roughly constant in a pilot training application. Figure 1 is an example which illustrates this by comparing two steps in a landing sequence. At six miles from touchdown (Figure 1a) a large number of light points are in view but very few solid surfaces may be seen. As the approach continues, light points pass out of view, while visible surfaces grow in size and number. At runway threshold (Figure 1b), only a few light points are in view while numerous surfaces of significant size are present.

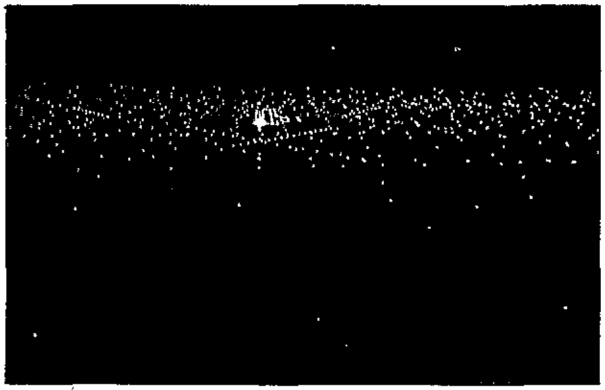


Figure 1a. 6 Miles from Threshold

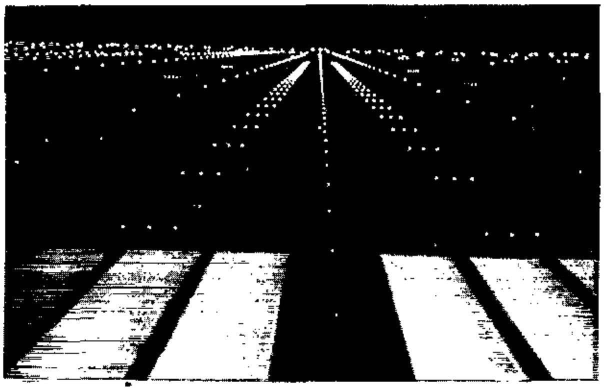


Figure 1b. R. W. Threshold

The sequential nature of calligraphic techniques fits hand-in-hand with such scene requirements in that writing time may split between precision point and surface display as required by instantaneous scene content. While calligraphic light point display has for some time been successfully performed with a jump-settle-unblank sequence, efficient generation of smoothly textured surfaces has been the subject of much research.

VITAL surface generation (Figure 2) implements a calligraphic technique uniquely developed for the VITAL application, which eliminates earlier problems. The surfacing device, descriptively named "Raster Blaster," is pipelined between a general-purpose computer and a high-speed color graphics display unit. The Blaster is designed to generate precision points and surfaces of uniform texture with minimum computer intervention. It contains the complete functions beam steering, blanking, surface shading, along with the control of color, intensity, and focus. A detailed description of the device and its design follows.

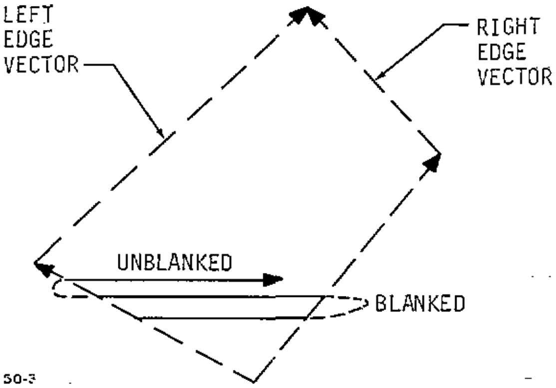


Figure 2. Vital Shape Generation

VITAL System Concepts

The Virtual Image Takeoff and Landing (VITAL) system was formulated as a solution to a particular visual simulation problem. That problem was one of twilight and night takeoff and landing under a variety of visibility conditions. Several unique design concepts, particularly in the area of surface generation electronics, were used to satisfy the requirements posed by this application.

The system (Figure 3) is partitioned into four elements: 1) system inputs, 2) image generation equipment, 3) picture controller (Raster Blaster), and 4) display electronics. This third element, the Raster Blaster, is the key to system performance. Its function is twofold; first, to generate control signals for display of points, and second, to generate control signals for display of surfaces. Because of its special advantages the surface generation concept will be discussed in detail.

A surface is defined in terms of its outline, represented by a segmented right-edge vector and a segmented left-edge vector. The beam is moved in alternate directions at a constant velocity and with a fixed separation between horizontal lines within the surface bounds. Constant beam velocity and separation are critical to achieving uniform intensity over the entire enclosed area. Efficient use of the deflection system is made by writing in both directions rather than using a blanked retrace. To aid in maintaining constant beam velocity and line separation, the beam is blanked outside the shape bounds and time allowed for beam settling.

In the Blaster, surface reconstruction is performed by the X and Y computers, and by the sweep generator. The X computer incrementally generates a representation of the left and right edges of a surface by adding a ΔX to the current X value each time the beam is incremented by one raster line, ΔY. Storage is provided for the several ΔX's required to generate a segmented edge. The Y computer generates current vertical beam position and compares it with the Y coordinates of edge vector breakpoints. The breakpoint comparison information is used to select the proper ΔX's for use by the X computer. The sweep generator defines instantaneous horizontal beam position. Sweep direction is controlled by comparing beam position to right and left-edge position. To reduce processing time during beam turnaround, the X and Y computers operate as separate pipelines, calculating data ahead of the time of its required use in beam positioning. The X computer serves a dual purpose in that it uses portions of the edge logic as a lightpoint pipeline.

Much of the geometric appearance of CGI scenes is removed by applying shading to surfaces. Figure 4 illustrates the effect continuous shading has on scene quality. With shading, a realistic tapered horizon glow is provided, fading smoothly as angle above the horizon increases. Intensity taper on the runway surface provides a depth cue and may be used to represent the effect of landing lights on surface visibility.

Intensity taper is under full control of software. The Z computer uses software supplied shading coefficients in combination with horizontal and vertical deflection signals to produce an interpolation of intensity simultaneously in X and Y. To represent a background illumination in conjunction with intensity taper, as would be found in a twilight landing scene, the Z computer has provisions to clamp intensity to a program controlled minimum level.

Focus control logic operates on the CRT focus amplifier to produce light points of a controlled size regardless of color. It may also be used for commanding defocus of points or shapes as required by special applications. It is possible to expand focus control to include a focus taper, much like the intensity taper.

Design Considerations

While simple in concept, numerous considerations entered into the final design. Design characteristics of special importance were first defined. These characteristics were matched to potential implementations and then evaluated through methodical testing. Quite often this meant scrapping a design and starting over.

Design goals of special importance to the VITAL form of point and surface generation were:

for points -

- provide point capability for standard approach and runway patterns along with miscellaneous background lights and landmarks.
- allow settling time that is a function of deflection distance.
- arrange points in strings to reduce average deflection distance.
- pipeline data transfers to minimize effects of I/O data rates.
- provide separate adjustments for color geometry (gain, offset, rotation, brightness).

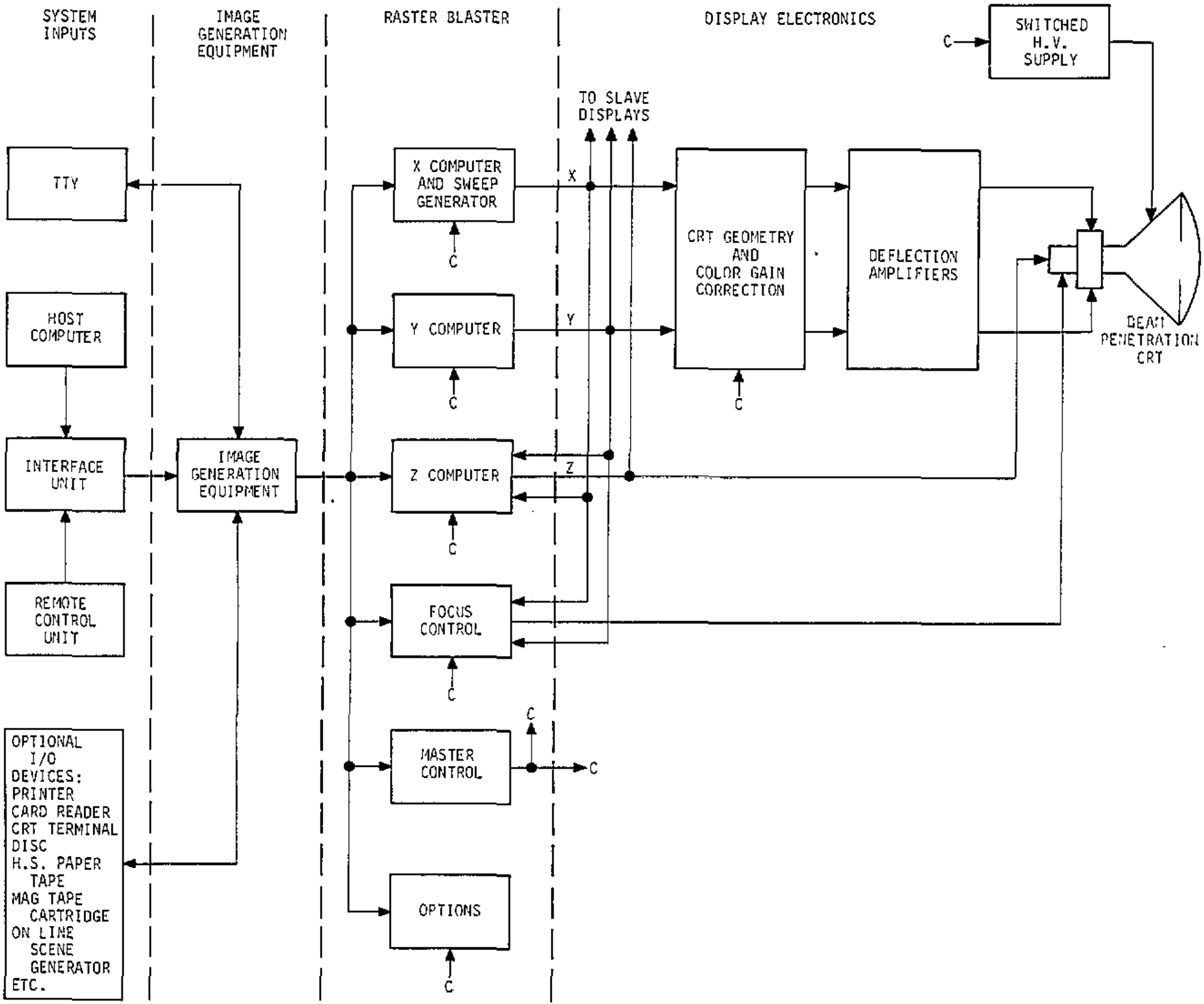
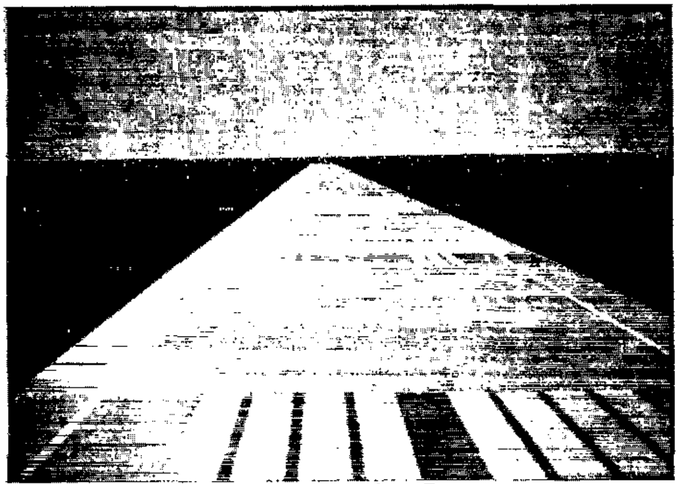
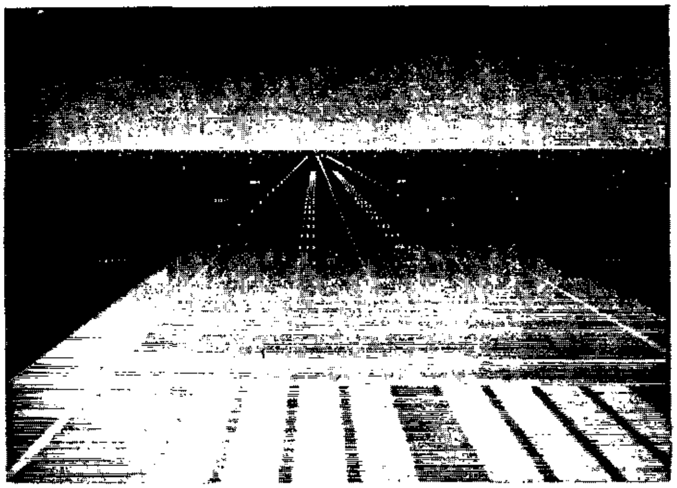


Figure 3. The Vital System


a. No Intensity Taper


b. Tapered Horizon and Runway Intensity


c. Variation of Intensity Taper - Right Outboard Landing Light On

Figure 4. Effects of Intensity Taper

for surfaces -

- achieve writing rate sufficient to present a horizon glow, runway surface with standard markings, and other special elements such as taxiways and key buildings.
- maintain intensity uniformity over a single surface.
- generate a tapered surface intensity (surface shading).
- provide good edge sharpness.
- avoid edge ripple and face flicker.
- maintain a solid appearance.
- correct for differences in transport delays between deflection and intensity channels.

For the most part, design goals for point presentation were met without the need for fanfare. Surface generation, however, provided some interesting design problems. A few of these are summarized in the following paragraphs.

Decreasing line density increases effective surface writing rate. As line density increases, beam defocus is needed to eliminate visibility of individual lines. Defocus must be used with caution, as surface edges tend to lose definition. Experiments showed that when this was applied to small surfaces, they had a definitely defocused appearance which in some cases was actually more annoying than the visibility of individual lines. Reducing line density also increases the detrimental effects of edge ripple and face flicker on small surfaces. This approach can still be used effectively if applied with care to drawing only large surfaces such as horizon, cloud top and runway; using high-line density for small surfaces.

Writing on retrace, while decreasing surface display time, requires precise control of beam position to prevent noise effects. Much of the design effort has gone towards achieving this control. As can be seen from Figure 5, the beam must be moved quickly and smoothly from one raster line to the next. At high deflection rates CRT brightness is highly dependent upon beam dwell time. Any vertical overshoot, when positioning to a new raster line, generates a potential for the beam overwriting an area covered by a previous raster line. Overwriting alters dwell time, subsequently altering brightness, much as increasing film exposure produces a brighter photo. The regular pattern generated is very noticeable. Vertical undershoot has the effect of reducing uniformity of line density. The partial overwriting that occurs at shape edges, produces edge brightening and increases the visibility of individual line pairs. Care must be taken to select a D/A converter and amplifier combination for Y deflection that minimizes conversion glitches, so as not to aggravate the settling problems.

Horizontal deflection linearity is equally critical to picture quality. Variations in horizontal writing rate produce effective changes in dwell time, with resulting intensity variations. In addition, nonlinear deflection induces errors in edge placement. Horizontal deflection anomalies result from amplifier response factors plus some characteristics that are inherent to the sweep generation method. Amplifier considerations are similar to those for vertical deflection. The sweep generation method must be free from turnaround instability and rate variations. Several possible methods of analog sweep generation are illustrated in Figure 6. Digital ramp approaches were avoided because of the high update rates required for low-position granularity.

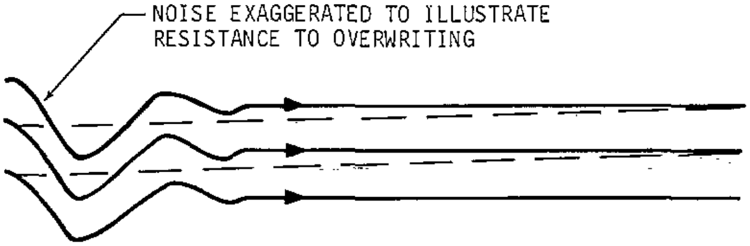
The most common approach, an operational amplifier integrator (Figure 6a), while possessing excellent linearity, suffers from output spikes on turnaround, resulting in deflection ringing. Causes are twofold; input to output coupling through the feedback capacitor and amplifier small-signal bandwidth, both difficult to deal with at the frequencies of interest.

Alternately charging a capacitor from balanced voltage sources (Figure 6b), while free from turnaround spikes, suffers from rate variations. Reasonable charging linearity can be obtained only when the source voltage is much larger than the maximum capacitor voltage.

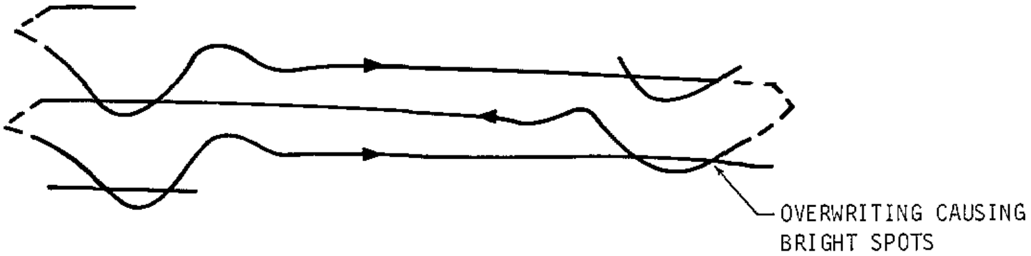
Alternately charging a capacitor from balanced current sources (Figure 6c), offers both good linearity and freedom from turnaround spikes. Practical current sources may be built operating with voltages very near the desired peak capacitor charging voltages. This was chosen as the most suitable method for VITAL.

Dwell time effects on brightness and edge precision weighed heavily in the selection of the VITAL writing techniques from among those shown in Figure 7. Some pros and cons of techniques considered are:

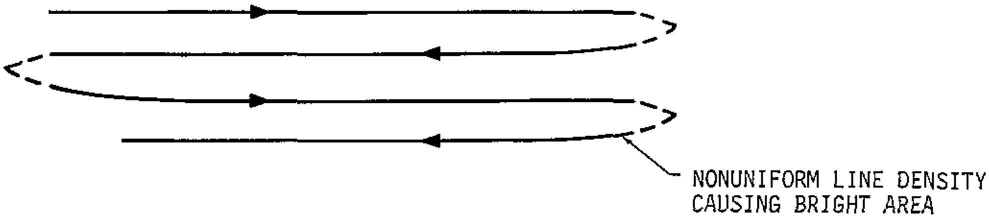
- Vector outline - Good edge definition, but no texture.



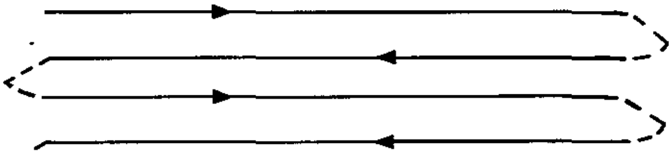
a. Blank on Retrace



b. Write on Retrace-Y Underdamped

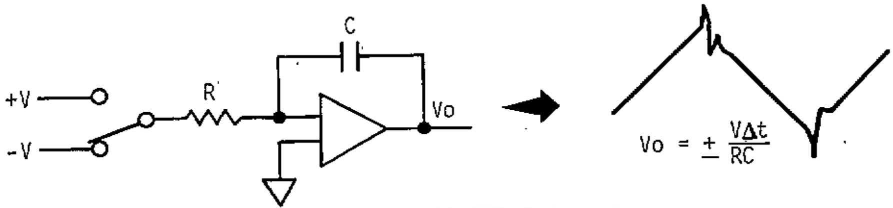


c. Write on Retrace-Y Overdamped

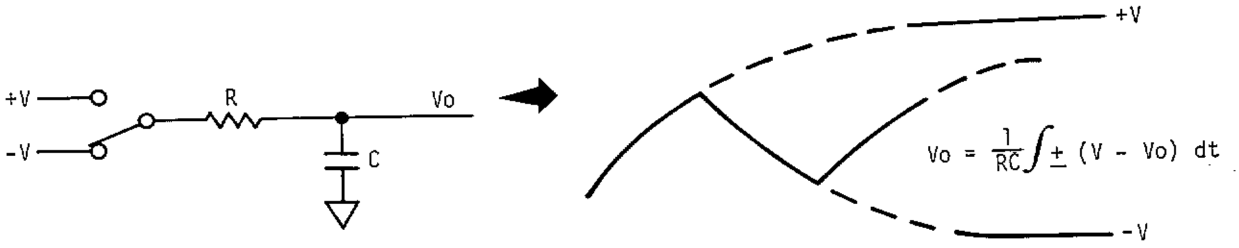


d. Write on Retrace-Y Properly Damped

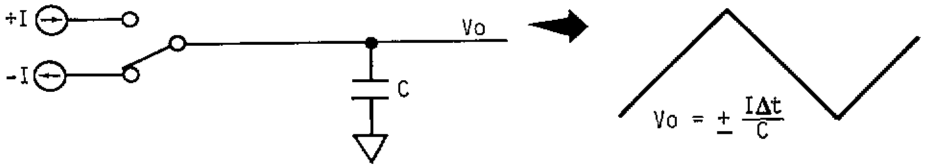
Figure 5. Effects of Nonuniform Line Density



a. OP-AMP Integrator



b. Capacitor Charged from Voltage Source through Resistance

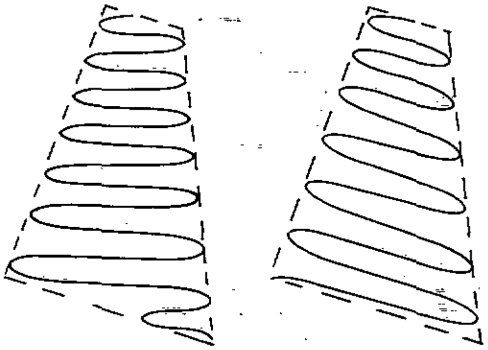


c. Capacitor Charged from Current Source

Figure 6. Analog Sweep Generation

a. Vector Outline

b. Transformed Vectors



c. Modulated Periodic Waveform

d. Truncated Parallel Vectors
(End Points Bounded by Shape)

e. Truncated Parallel Vectors
(End Points Outside Shape
Intensification Bounded by Shape)

Figure 7. Some Variations of Calligraphic Surface Generation Techniques

- Transformed vectors - Transformation of individual vectors is relatively easy. Volume of computations is high. Intensity and precision control is poor because of nonuniform line density.
- Modulated Periodic Waveforms - Better texture and precision uniformity than transformed vectors. Suffers from variable dwell time resulting in brightening of shape edges. Line density varies 50 percent between surface edge and center.
- Truncated Parallel Vectors (bounded by surface edge) - Capable of very uniform texture and brightness except at edge where practical deflection bandwidth limitations restrict beam position control.
- Truncated Parallel Vectors (end points outside surface edges, intensification bounded by edges) - Capable of very uniform texture and brightness over entire surface. Requires precise control of blanking.

The latter approach was taken because of extreme importance placed on surface uniformity Any regular distortion can act as a strong distraction, drawing attention from the scene itself. Blanking control requires considerations that are much more important than for a raster type system. Relative timing between the blanking and horizontal deflection signals is critical. With a raster scan surface, any timing mismatch results in positional offset of the entire surface (Figure 8a). The effect of timing mismatch on a write-on retrace surface is to create a shadow effect on the edges (Figure 8b). The VITAL blanking signal is delayed to compensate for deflection transport delay, thus removing the edge shadow. Blanking delay is adjustable to compensate for individual deflection variations.

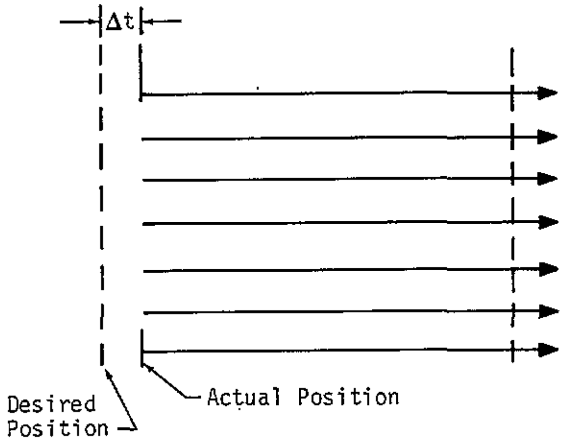


Figure 8a. Raster

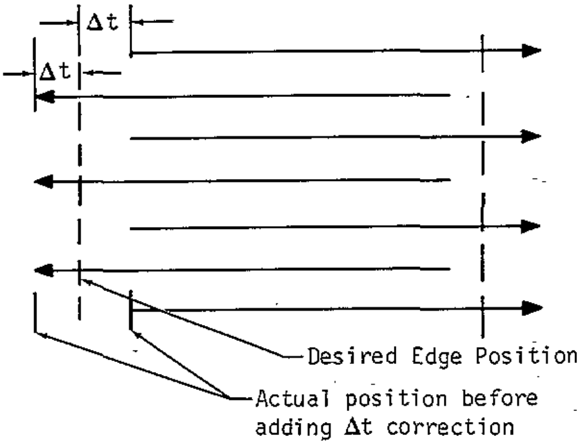


Figure 8b. Write or Retrace

Understanding the nature of deflection transport delay is necessary for proper delay compensation. The horizontal deflection chain gives the dynamic effect of a multiplicity of low-pass filters. Figure 9 gives the output of a simple low-pass filter with a ramp input. The output follows the input by one time constant except near the origin, where there is distortion. The blanking delay compensates for the combined time constants. Distortion near the origin produces a variable delay which could result in different matching requirements for small and large shapes. Deflection overscan is used to linearize the output before unblanking, minimizing delay variations. A tradeoff must be made between amplifier bandwidth (f_2) and overscan time, reduction of overscan requiring an increase of bandwidth. VITAL deflection bandwidth is sufficiently high to make linearity compensation delay a secondary factor.

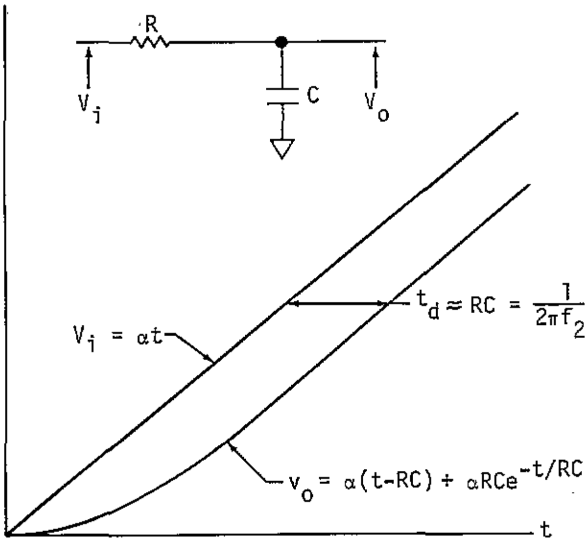


Figure 9. Distortion of Ramp Input by a Simple Low-Pass Filter

CONCLUSIONS

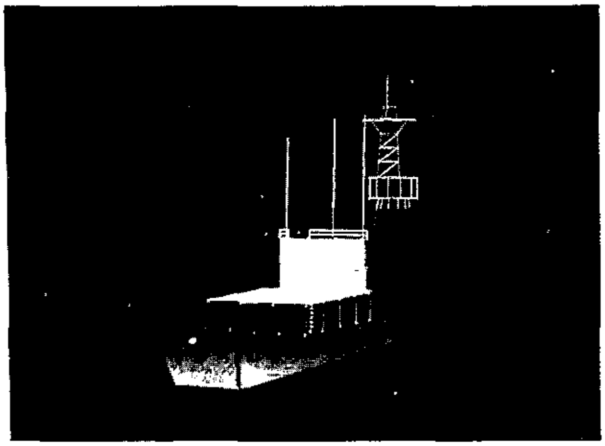
The Raster Blaster has demonstrated a distinct set of advantages. The outstanding advantage is the efficiency of serial lightpoint and surface generation. Serial generation means that the same set of common electronics may be used to generate each lightpoint and surface which appears in the scene.

The method of surface generation offers several advantages in itself. The compressed description of a surface by equations representing its outline, means low data rates between the computer and Blaster, freeing the computer to perform necessary processing. In addition, the effective split in computation load permits more efficient use of the computer's capabilities. The computer performs the relatively complex job of surface outline transformation and windowing, while the Blaster performs the simple but time consuming operation of incrementally generating the surface outline. Thus, for a given amount of computation power applied, a more complex scene may be produced.

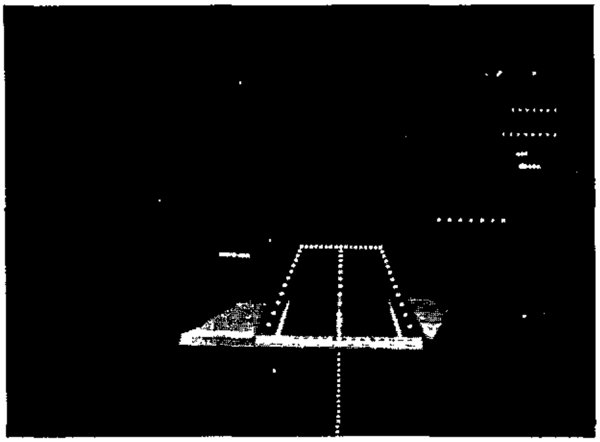
Uniform surface texture gives the appearance of solidity. Combined with computer controlled intensity taper, defined differently for each surface, illusion of depth is enhanced, producing an unexpected degree of realism.

The Blaster has not yet realized its full speed potential. As needed, effective system speed may be increased through improvement of the computer and display electronics. Computer improvements include expansion and the addition of special-purpose processing electronics. Display speed improvements can be made by upgrading the deflection system.

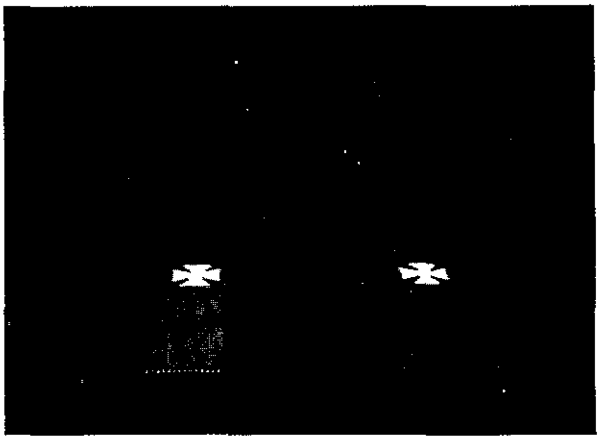
What was designed as a solution to the specific problem of takeoff and landing simulation has rapidly found application in a diverse and growing set of pilot training areas. A few application scenes are pictured in Figure 10. Ongoing research indicates that this new and yet open-ended technology is due to produce some pleasant surprises in the near future.



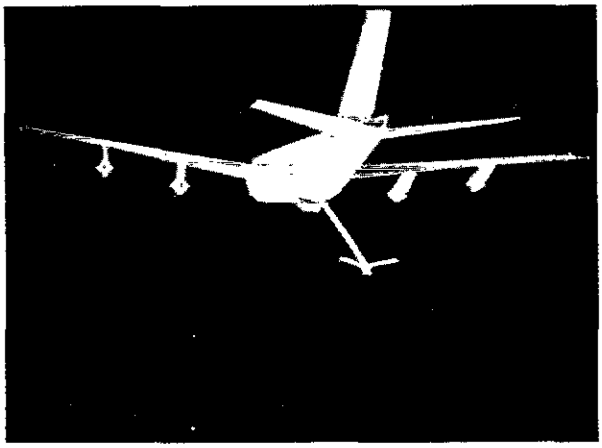
a. Helicopter Capable Fast Frigate



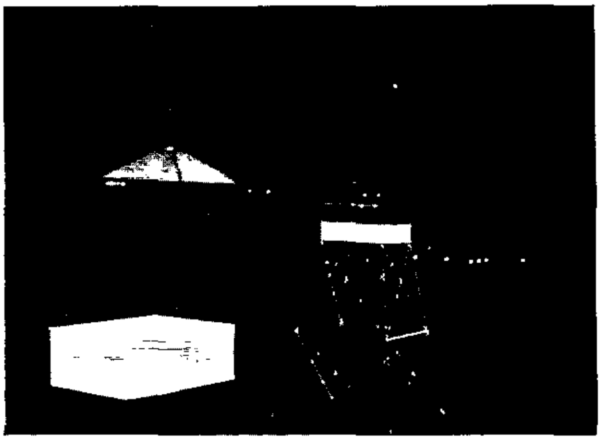
b. Carrier Landing Scene, JFK



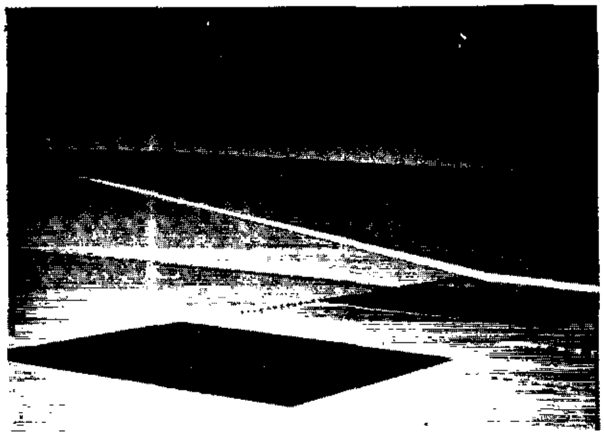
c. Multiple Runway Helicopter Staging Area with Maltese Cross Touchdown Zone Markers



d. KC-135 Aerial Refueling Scene



e. Helicopter Staging Field with Tower and Building in Foreground and Helicopter Landing Pinnacle in Background



f. Daylight Scene with Random Field Pattern

Figure 10. Vital Applications

ABOUT THE AUTHOR

MR. CARL J. VORST is a Senior Engineer at McDonnell Douglas Electronics Company and is responsible for development of the visual imaging electronics which are the heart of the VITAL series visual simulation equipment. Previously, his responsibilities included system design of a Digital Radar Landmass Simulator, and other assignments in the area of system interface technology. Mr. Vorst received a B.S. degree in Electrical Engineering from the University of Missouri.