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VTOL/STOL VISUAL STUDY

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1.0 INTRODUCTION

NASA/Ames procured a digital visual system from LINK Division of the Singer Company. This system was designed for use with the Vertical Motion Simulator to perform basic studies on VTOL/STOL (Vertical/Short Takeoff and Landing) aircraft. The visual system was a production of the F-111 systems procured earlier by the Air Force with a few minor modifications. Basically the modifications were:

- the addition of a visual channel (from three to four channels),
- the use of a vertically scanned display instead of a horizontally scanned display,
- the addition of VTOL/STOL runways to the Plattsburgh and Pease airdrome data base, and
- the inclusion of two ships (an LPH and a Spruance class destroyer) in the data base.

Because the visual system was basically a production follow-on, it was difficult to include in the contract unique visual effects that were developmental in nature yet would be highly desirable for the VTOL/STOL research task. Among these important visual effects are such considerations as realistic sea state, bow and stern wake, and ship motion without implementing complex ship/ocean priority computations. Until now these effects in digital visual systems have been somewhat crude because of limited image processing capability. Therefore the visual effects produced have been unsatisfactory.

A Study Contract was awarded to LINK to develop data bases and/or real-time techniques to improve the realism of sea state, bow and stern wake, and ship motion. Experiments would be performed on the LINK Research Visual Simulator in their Sunnyvale Laboratory.

This report presents the results of LINK's study. LINK has prepared 35 mm slides and a 16 mm film portraying this work.

2.0 SCOPE

Since the NASA/Ames simulator is experimental in nature, it was difficult to predict beforehand what special visual effects might be required. A great many possibilities unique to naval operations were reviewed with the technical personnel at NASA/Ames. Among those not previously mentioned were smoke, clouds (other than the standard visibility effects), rotor downwash, own shadow, landing officer hand and wand signals, white caps, and bow and stern wake as a function of history. It was agreed that although these effects were useful and would be of eventual interest, the basic modeling techniques necessary for sea state, bow and stern wake, and ship motion would demonstrate that the others could be implemented when time and funds permitted.

It was further agreed that the techniques devised should be as simple as possible to achieve the desired effects. Edge generation capabilities of the visual system would not be expended at the cost of overall scene complexity. Since the visual system was a production follow-on, none of the proposed visual effects could involve further hardware changes and hopefully software modifications would be kept to an absolute minimum. The latter consideration excluded using additional moving objects for these effects. These restrictions limited the effects being produced to additional data base modeling, data base rearrangement, or small real-time subroutines that could be called.

Wherever possible, the solutions were to be modeled and displayed in real-time on the LINK Research Visual Simulator for evaluation by NASA/Ames technical personnel.

3.0 PROGRAM

Few visual perception studies have been performed using digital visual systems much less studies directed toward requisite ocean/ship effects. Past experiments on terrain features, runways, etc. do not necessarily apply to sea state or ship wakes. Without benefit of previous literature or experiments in this technical area, basic assumptions had to be made regarding pattern sizes and, in some cases, the repetition rate of the patterns. These variables can be further investigated at some later date.

3.1 Sea State

3.1.1 Static 3D Waves

It was assumed that LINK had no previous experience in making 3D waves and, therefore, could not predict the appearance of irregularly modeled mounds (as it turned out, not unlike the method of building mountains). These "mounds" were scaled smaller than hills and coded blue rather than green. When the results of the first model were displayed, it became apparent that the problem with 3D waves is identical to the problem with the appearance of low hills in nap-of-the-earth flight. The problem is that there is little difference in the shading of the faces that make up the "mounds". When smooth shading (Appendix I) is applied, any resemblance to a 3D feature and any indication of shape is totally washed out (see Figure 1).

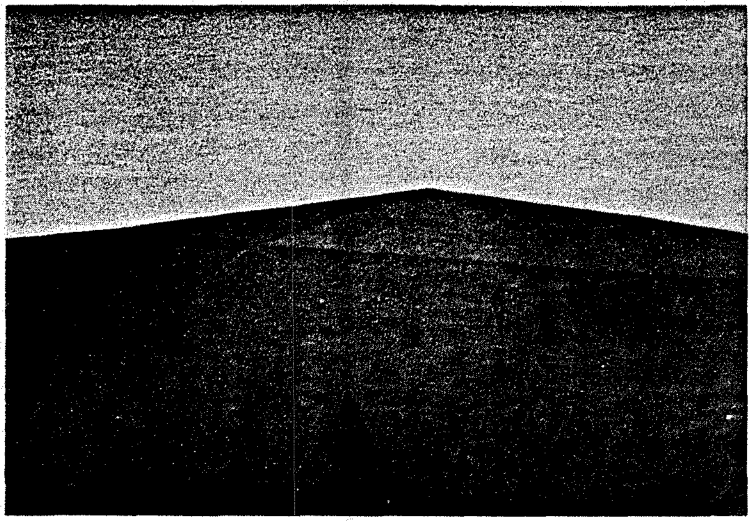


Figure 1
3D Static Waves

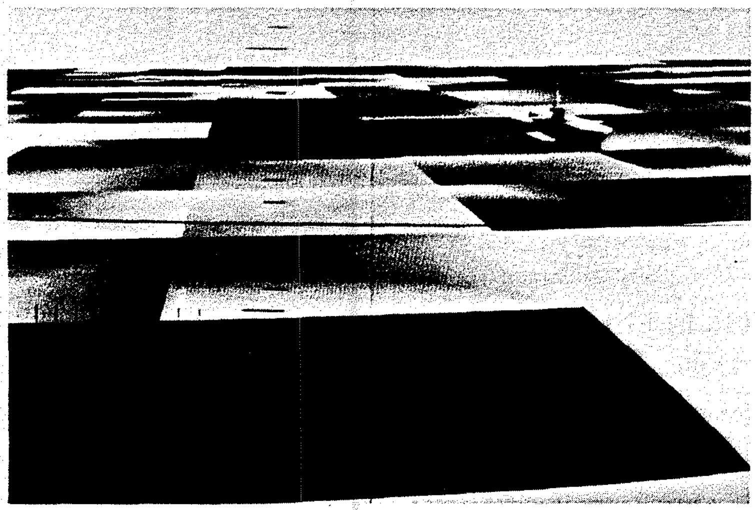


Figure 2
Ocean Surface
(Without Smooth
Shading)

Figure 3
Ocean Surface
(With Smooth Shading)

On other military helicopter programs, LINK investigated many modeling techniques to alleviate this problem. Among these techniques were overly accentuating sun shading, outlining faces in 3D objects, and placing a checkerboard pattern on 3D features. Whereas these techniques can be somewhat accepted by the viewer in terrain (there are regular field patterns in many areas), they are totally unacceptable in an ocean scene.

3.1.2 Moving 3D Waves

Translating the 3D pattern would not change its appearance (over a static 3D pattern) because the sun angle with respect to the faces would not change. Therefore, several other techniques were suggested and the effort to implement them estimated. These techniques included rotating the 3D objects, switching 3D objects in and out of the scene (leveling), etc. All were difficult to implement and did not give promise of providing a useful and desirable visual effect even if the implementation were successful.

At the same time that this part of the study was being carried out, work was progressing on the 2D approach to sea state. Some of the early results of the 2D investigation appeared to offer better visual effects than the 3D efforts and further work was concentrated on the 2D patterns.

3.1.3 2D Sea State

The first attempts to develop sea state were made utilizing a static 2D pattern. Several different regular patterns were modeled and displayed. Although these types of patterns have been tentatively accepted for nap-of-the-earth flight (UH-60A simulator), their regularity makes them disconcerting for expanses of water. Originally we had assumed that the patterns could be modeled with subtle differences in intensity so that the appearance would not be objectionable but the eye is much too sensitive to even slight intensity changes, particularly along straight lines between faces. An example of a nonsmooth-shaded regular pattern with many intensity levels is shown in Figure 2.

These patterns were also modeled so that they could be smooth shaded. That is, the intensity between faces was extrapolated along each scanline so as to eliminate the sharp discontinuity in intensity from one face to the next. It was presumed that this "smoothing" in a 2D pattern would be sufficient to give a visual impression of ocean surface.

The pattern of Figure 2 was smooth shaded and is shown in Figure 3. This is obviously an improvement over a non-smooth-shaded sea state. However, the scene appeared much too static and lifeless to properly convey an ocean surface. For this reason, it was decided that a method of changing the apparent intensities of the ocean patterns as a function of time would be highly desirable.

3.1.4 Dynamic 2D Sea State

The basic approach in generating a dynamic sea was to model a pattern of smooth-shaded faces with modified vertex normals. Since the cross-product of the vertex normals and the sun vector controls the shading of the faces, many different patterns can be generated by modifying vertex normals while the contrast of these patterns can be increased by moving the sun downward from the zenith. The latter is shown clearly in Figures 4, 5 and 6. Figure 4 was taken without a sea pattern and Figures 5 and 6 show the contrast of the smooth-shaded sea pattern at two different sun angles.

The initial implementation of this approach was to modify the vertex normals in the object descriptions of the sea pattern in a predetermined sequence. This would cause the faces to change in a cyclic sequence. It was determined that it was necessary to update the normals at display frame rates to prevent noticeable stepping between patterns.

Updating the normals at frame rates proved to be an extremely difficult software task and the time necessary for its execution exceeded the available CPU time. A simpler method of implementation was then developed as follows (see Figure 7). A single sun vector is normally sent each frame for all objects in the data base. By separating the objects for the sea pattern, it was possible to assign a second sun vector for this particular group of objects. Computing only a new sun vector each frame for the entire sea pattern made it possible to achieve the same visual appearance as the original attempt at implementation (updating each of the face normals), but with considerably less real-time software. The single sun vector computation for the sea state required less CPU time in the real-time software than in the initial face normal implementation. With only one vector to change, it was also possible to use a more complex vector modification algorithm.

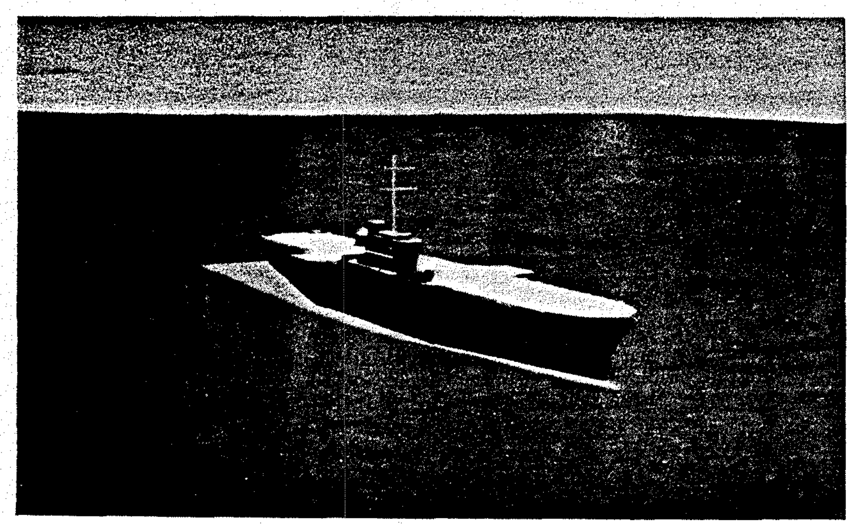


Figure 4

Sea State 0
(No Pattern Contrast)

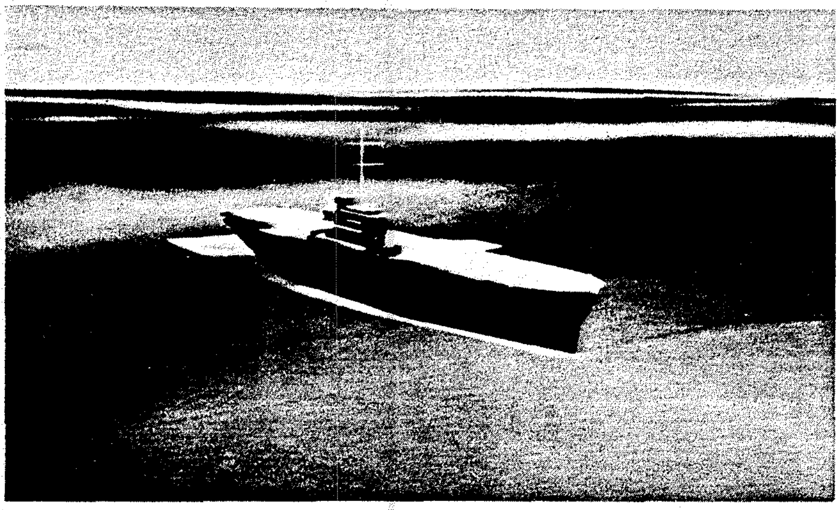


Figure 5

Sea State 1-2
(Moderate Pattern
Contrast)

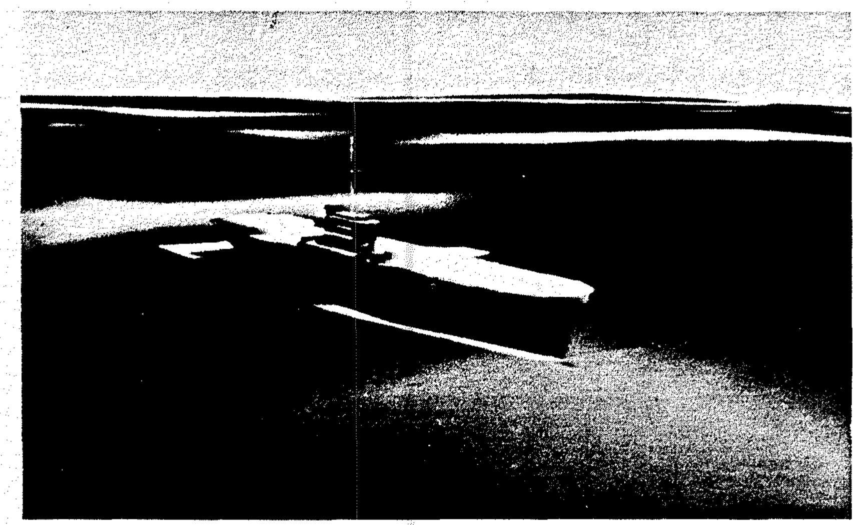


Figure 6

Sea State 3
(High Pattern
Contrast)

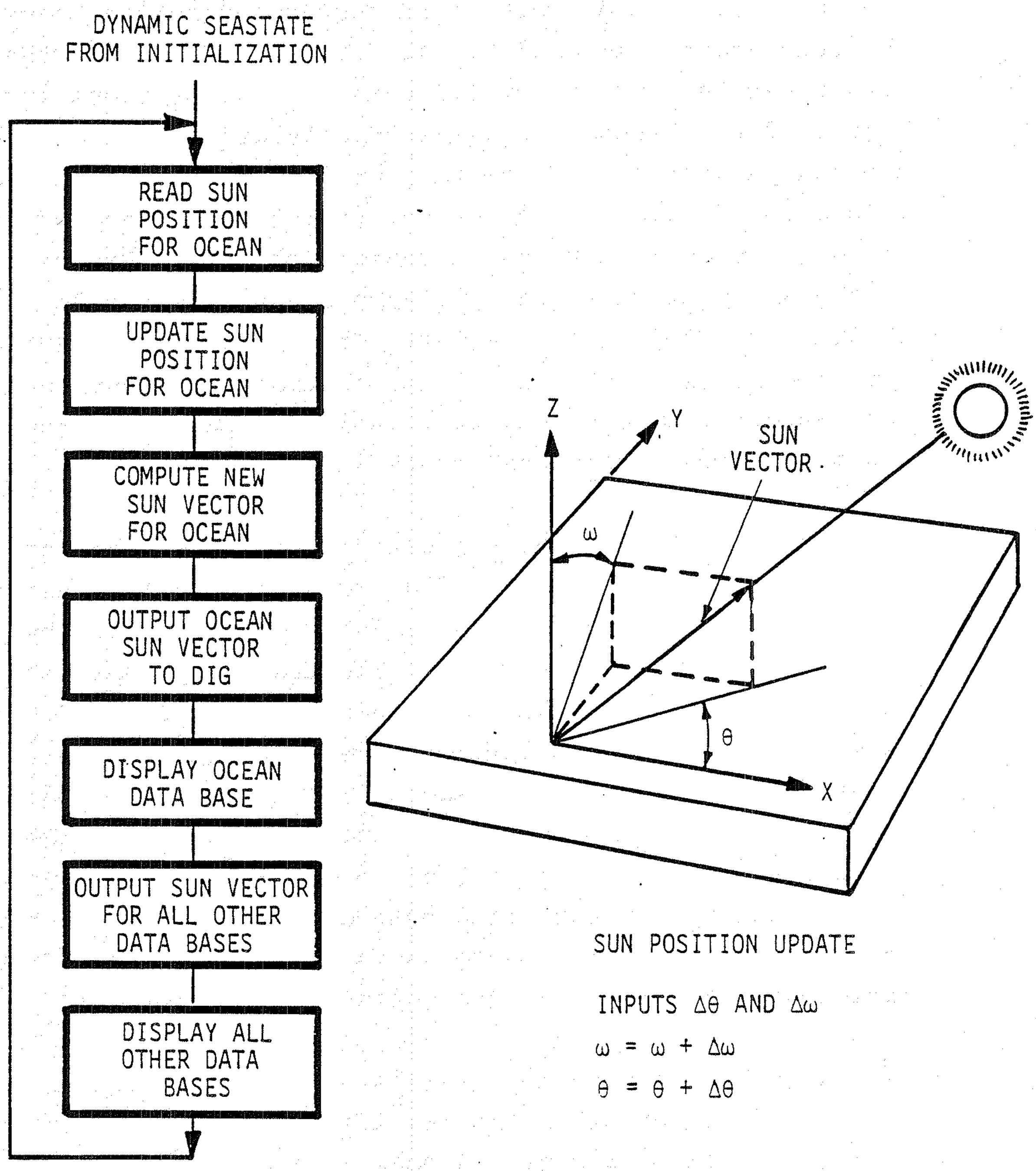


Figure 7 Dynamic Sea State Technique

The sun vector, when rotated in a circular motion, causes the sea patterns to change realistically. Changing the rotation rate simulates various agitations of ocean surface. Figures 8 and 9 show how the intensity of each square in the sea pattern changes as the sun alters its position as a function of time. The smooth shading was turned off for these pictures to make the technique obvious. Figure 10 is the sea pattern shown in Figure 9 with the smooth shading turned on. This effect, coupled with the fact that the angle of the sun vector controls the contrast on the pattern (as described previously) is useful in generating a number of different sea states.

The faces comprising the sea pattern were digitized as illustrated in Figure 11. If a smooth-shaded face has more than 3 vertices, the face is divided into triangles by the digital image generator as illustrated by the dashed lines in Figure 11. This particular method was used because it makes the resulting pattern have peaks and dips with the fewest number of faces and edges. A complete discussion of the digital visual system's technique to smooth shade objects and how this is applied to 2-D surfaces is included in Appendix 1. An automatic method to assign vertex normals to produce various sea patterns is also discussed. Three different patterns of vertex normals were examined:

1. When the vertex normals were assigned in a random basis, the resulting dynamic pattern was that of a confused sea.
2. When the vertex normals were computed as a sine wave on odd rows and its mirror image on even rows, the pattern looked unrealistically distinct.

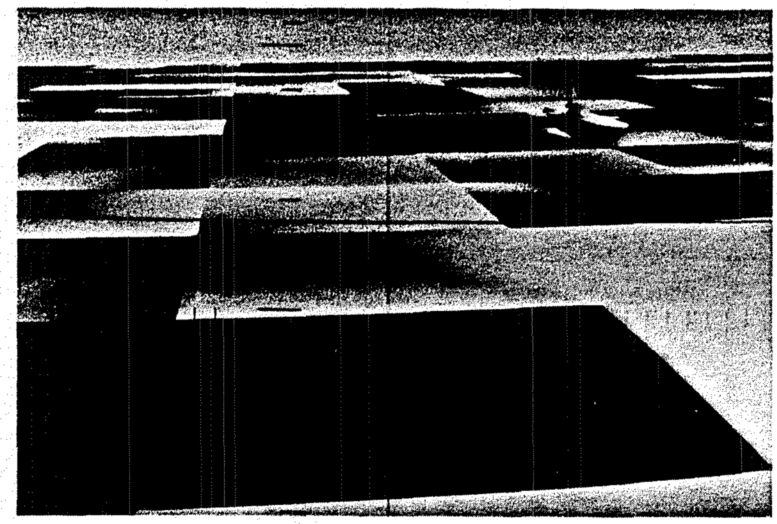


Figure 8

Ocean Surface
Time = t_1
(Without Smooth Shading)

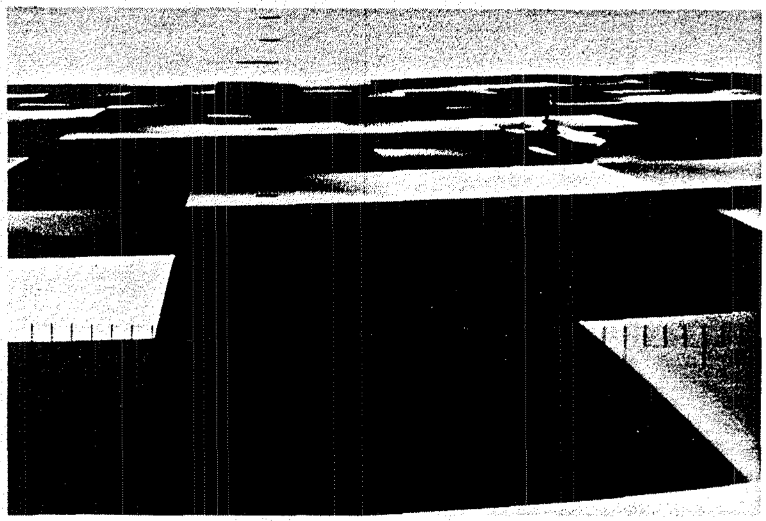


Figure 9

Ocean Surface
Time = t_2
(Without Smooth Shading)

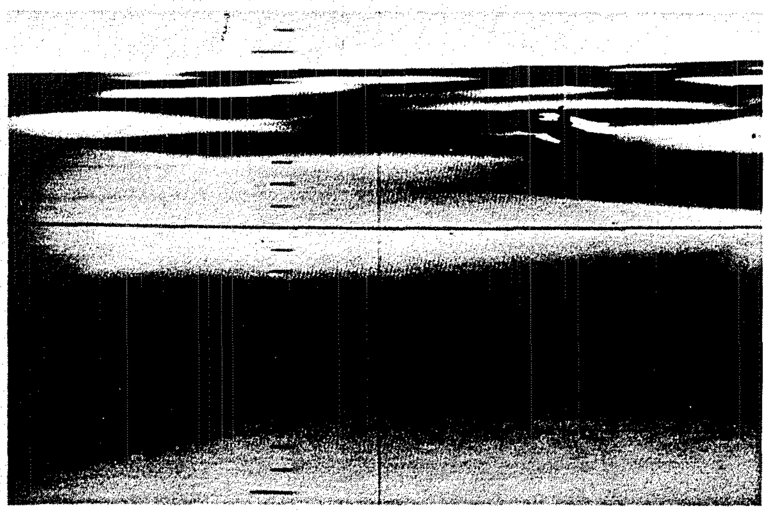


Figure 10

Ocean Surface
Time = t_2
(With Smooth Shading)

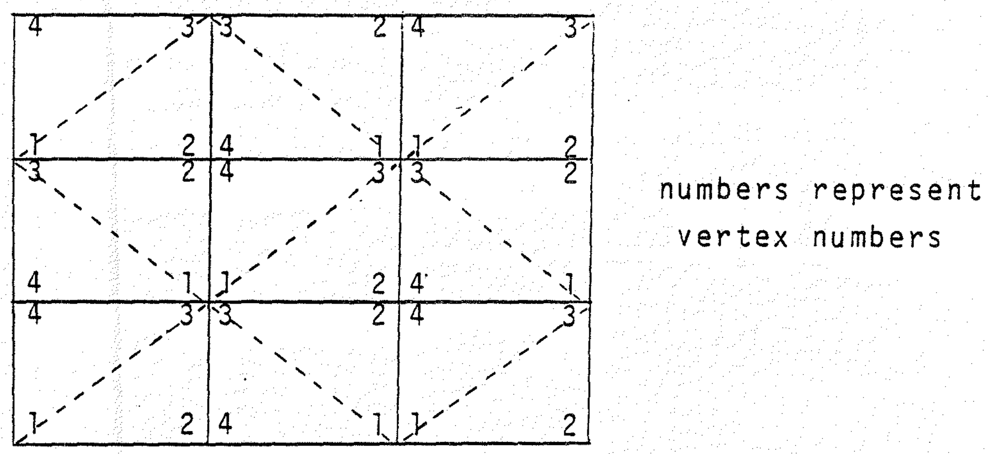


Figure 11 Face Digitization

3. When the vertex normals were computed as a sine wave on all rows, the pattern appeared as a series of bands moving in parallel, not unlike ocean swells.

Of the three patterns mentioned, the random pattern appeared to be the most acceptable visually and was incorporated into the simulator.

3.2 Bow and Stern Wake

3.2.1 Bow and Stern Wake Simulation

Previous modeling of ship bow and stern wakes were simply modeled data base faces, usually in the shape of a white "V" beginning at the bow of the ship and abruptly terminating a fixed distance behind the ship. These faces overlaying the large blue faces that comprised the ocean provided a completely unrealistic and undesirable visual image to the pilot. Duplicating this procedure on the research simulator demonstrated that clever "blending" of colors through the use of numerous faces and smooth shading did not wholly satisfy the observer. It was decided that no modeling approach would be satisfactory unless it were dynamic.

3.2.2 Face Substitution

In an attempt to generate moving objects such as the ship bow wake, many different schemes were considered. Usually these amounted to a wake moving object which traveled with the ship. Efforts were made to make the complex bow-wave motion using the simplest real-time motion possible. Initial attempts made the moving object in the shape of a cam. As the object rolled about its axis (as it moved with the ship), it would continously present a different shape (and height above water) to the eye. The implementation of this scheme proved to be quite laborious and required two real-time moving objects (one for each side of the ship) involving many scene edges.

Attempts to simplify the "moving object" procedure indicated that a method would have to be developed that was a radical departure from the straight-forward approach. After several attempts, the movie industry animation methodology was employed and a series of sequenced faces were used to make an object enlarge and decay in a programmed fashion. A procedure was developed whereby all of the sequential faces were made part of the moving object with which they were associated--in our case, with the ship moving through the sea. This procedure is shown graphically in Figure 12. Four actual frames taken from the display are shown in Figure 13. As the moving object was transferred from the active data base, one of the bow-wake faces was transferred with it and subsequently displayed. After a fixed number of frames, a pointer would substitute a second face for the first and subsequently display it with the ship. The rate at which the subsequent faces were transferred and the difference between subsequent faces produced the dynamic movement. The selection of these two parameters along with the selection of various colors can be used to produce a wide range of effects.

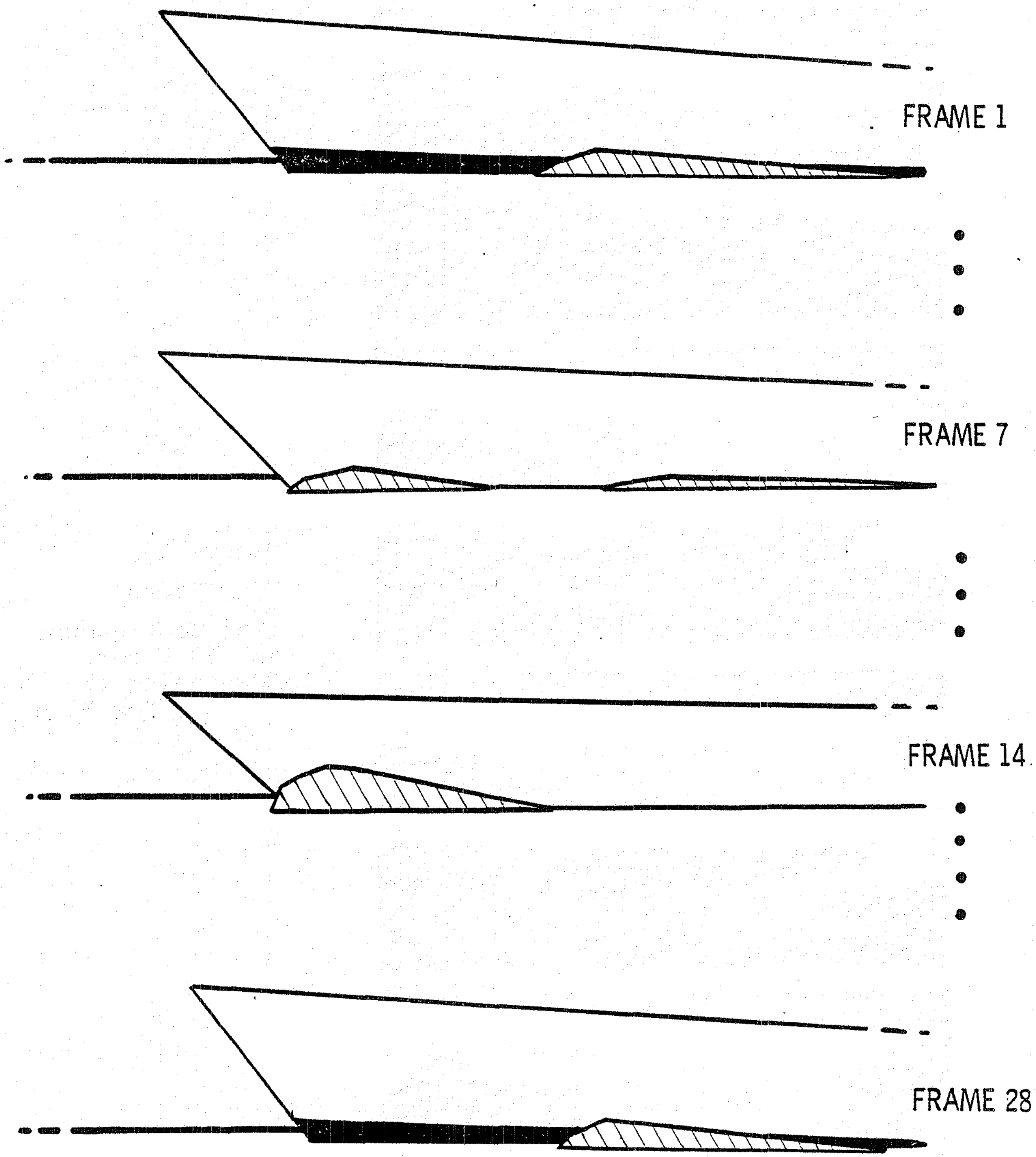


Figure 12 Moving/Growing Objects (Bow and Wake)

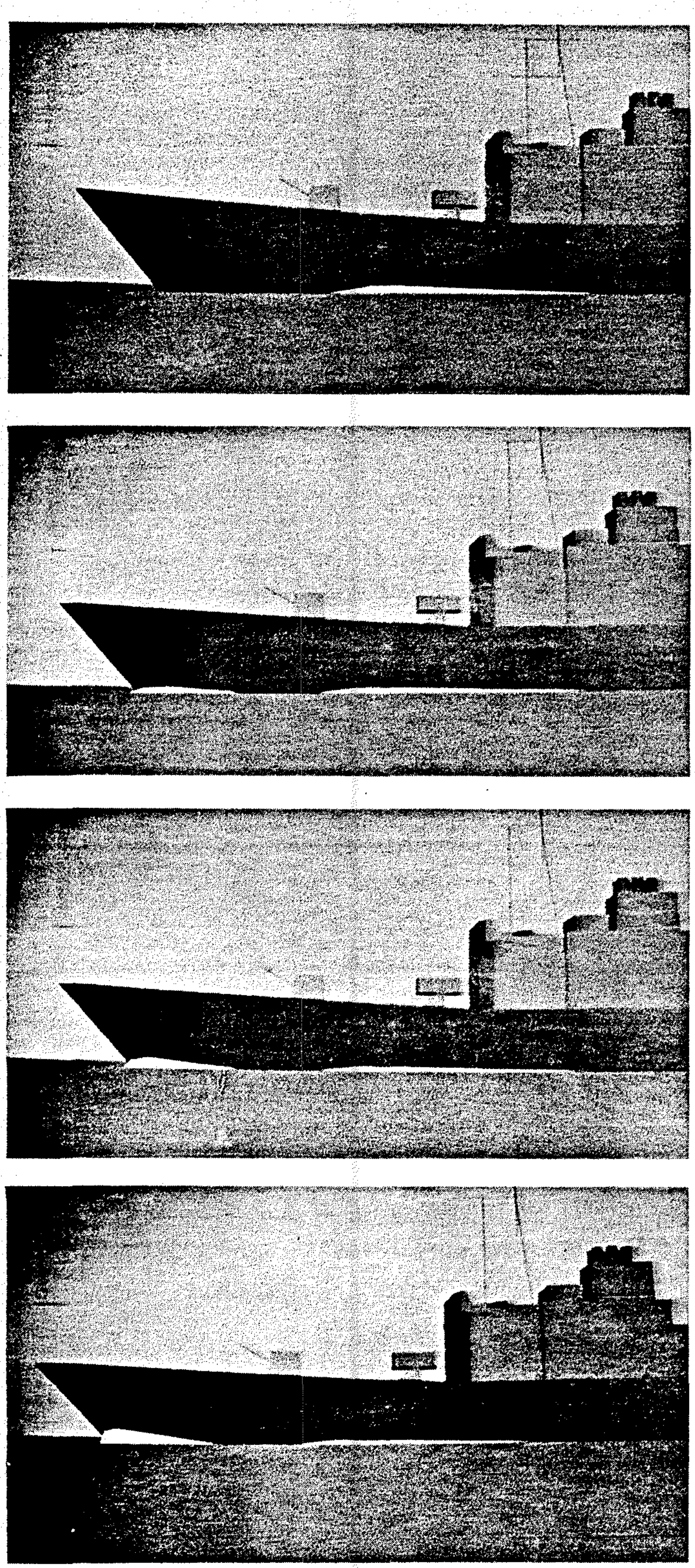


Figure 13

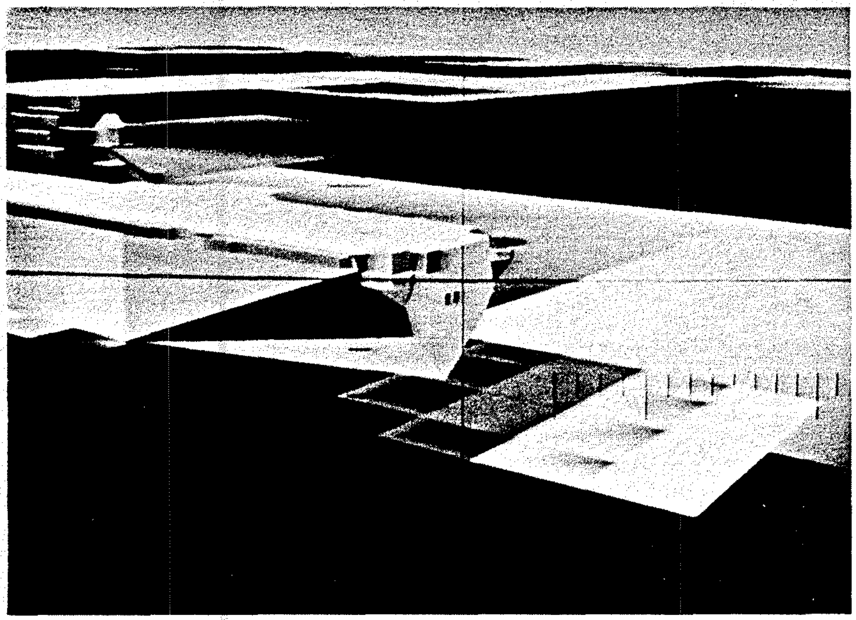
Four Faces

(Not Contiguous) of the 28 Faces Comprising the Dynamic Bow Wake Pattern

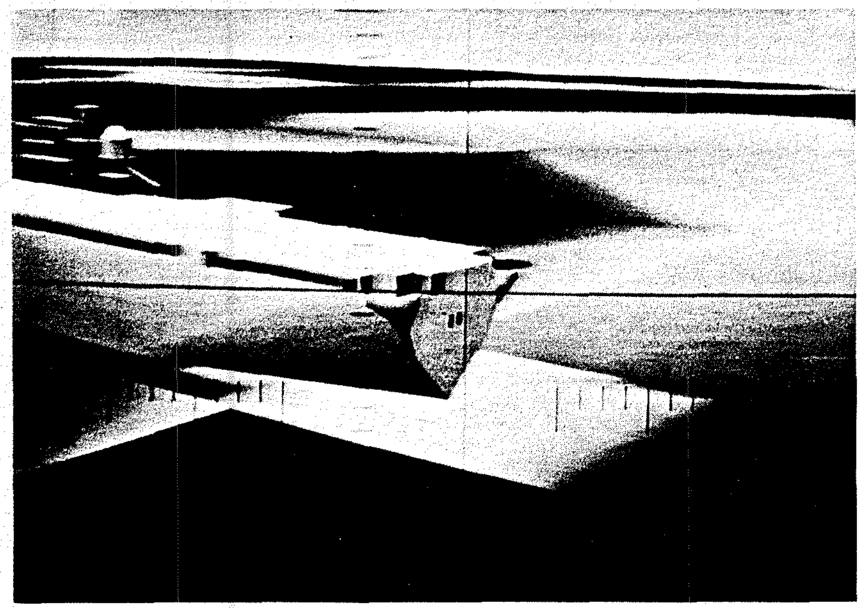
This technique of effectively modifying the digital data base in real-time gave rise to many of the other effects disucssed herein.

3.2.3 Use of Modified Sea State Pattern

The bow wake generated as described in Section 3.2.2 was extremely realistic when viewed from an eye position close to the surface of the sea. However, when observed from near vertical the faces comprising the bow become almost invisible (the faces have no thickness). Attempts to make the bow a 3D pattern turned out to be complex. (Later work on object substitution, would have simplified the implementation, but these techniques were developed too late in the program to be thoroughly investigated.) It was then determined that the design approach used to implement the sea state pattern could also be used for bow and stern wake. Several patterns, pattern colors, pattern sizes, sun vector angles, and sun vector speeds were modeled and displayed on the research simulator. After several iterations when the speed of the sun vector rotation was increased substantially, a "churned water" effect was created. Figure 14 shows the bow and stern wake taken from the research visual simulator. These images were demonstrated to NASA/Ames personnel and the pattern size shown in Figure 14 was selected for incorporation into the delivered simulator. A small hardware modification was incorporated into the delivered image generation hardware so that two of the levels of image detail were added together rather than the normal method of simply replacing one level of detail for the other. This



Stern Wake - LPH2 (Without Smooth Shading)



Bow and Stern Wake - LPH2 (With Smooth Shading)

Figure 14

means that the changing intensities of the pattern making up the ocean image were added to the more rapidly changing intensities of the ship wake pattern. This provided an even greater turbulent effect.

3.3 Ship Motion

3.3.1 Occulting (Ship/Sea)

The realistic portrayal of sea state demands a substantial amount of ship pitch and roll. Other ship movements such as heave and sway, are important to landing/takeoff simulation but do not make additional demands on the visual system. Personal communication with NASA/Ames technical personnel has established that landing and takeoff can reasonably be expected to be performed with pitch less than 5° and roll less than 8°.

The worst case for ship/sea occulting would be from a position close to the ocean surface. Viewed from this position, it appeared necessary to model to some distance below the waterline so that the hull can be seen when the ship is pitched up, and conversely, less hull above the waterline can be seen when the ship is pitched down. This causes a mutually exclusive visual object priority problem. If the ship has higher priority than the ocean, the ship can be seen below the waterline to the point that it was modeled (this makes it appear to "float" on the ocean at the lowest point digitized). On the other hand, if the ocean were to have higher priority than the ship, the ship would not appear except for the area above the horizon. Any occulting schemes that involved paths or seams in the ocean were discarded because they would permit only preprogrammed ship motion. The following is a discussion of methods that were experimented with during this program.

3.3.1.1 <u>"Moving Box" Occulting Method</u>

Occulting the part of the ship which is below the water can be accomplished by positioning a box (open at the top) around the ship from the waterline down. The box must be the same color as the surrounding water and must have a higher priority than the ship.

The assignment of color, intensity and priority of the box are easily accomplished. Color and intensity are chosen during modeling. The priority of the box is accomplished by making the box a separate object list and setting its priority during initialization of the real-time program to be greater (lower number) than the ship's parts.

The accuracy of this method decreases with increasing altitude of the viewing point. This accuracy can be maximized by making this box as close to the shape of the occulted parts of the ship as possible. The ship then appears to rise from and disappear into the sea when it actually is being occulted by the moving box.

This method was demonstrated to NASA/Ames personnel and is effective. However, a simpler method (using no moving object and fewer edges) is more desirable.

3.3.1.2 Face Substitution Method

It was originally assumed that if the ships were to be modeled only to the waterline (effectively "floating" on the ocean surface), an eyepoint close to the water would detect space below the bow and stern when the ship pitched up and down. Before the modeling of the ship was completed, several methods of occulting other than the moving object method discussed in the previous paragraph were investigated. The most promising of these was a modification of the face substitution method used for the bow wake. Basically, it involved using a series of wedge-shaped faces of progressively larger sizes to "fill" the space between the bottom edge of the ship (waterline) and the surface of the ocean as the ship pitched up, and the removal of the wedge-shaped faces as the ship pitched down. These would be inserted (or removed) in real-time as a function of the angle of pitch (see Figure 15).

(Roll is not a problem because the face used on the bottom of the ship appears to be simply the extension of that portion of the ship below the waterline exposed during roll.)

Several simple experiments were attempted and there is no reason to doubt that the method would work when fully implemented. However, two factors halted further investigation - one was that the amount of effort was greater than the budget allowed for this item and, more importantly, the completion of the actual ship model gave us better insight into the problem.

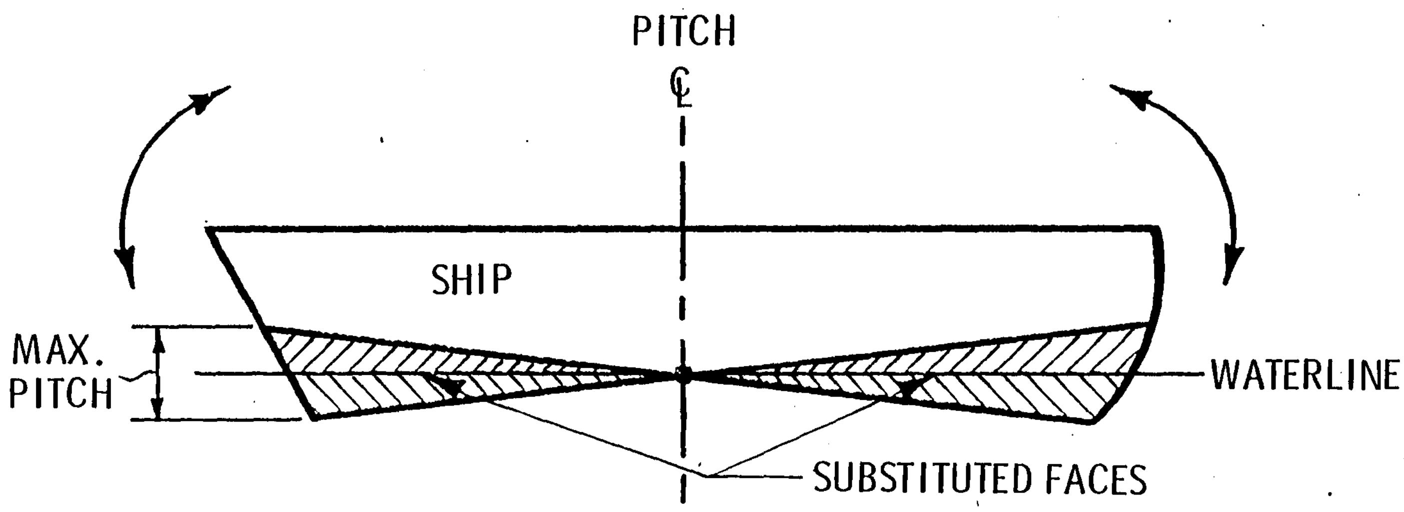


Figure 15 Face Substitution

3.3.2 Necessity of Occulting

When the modeling of the two ships (DD963 and LPH2) used for the study was completed, the LPH was programmed as a real-time moving object and driven realistically through the ocean data base. Pitch was programmed in as 10° which is double the maximum worst case excursion permissible in landing/takeoff (6.8° roll, 5° pitch as per NASA/Ames technical personnel). The LPH in these experiments was modeled only to the waterline. The completed scene was dynamically demonstrated to NASA/Ames technical personnel as well as to numerous other pilots. At no time during any of these demonstrations was any objection raised, nor was attention called to the fact that when the ships pitched down the length of the prow did not shorten. In fact, the comments were unanimous that the ships motion was "realistic". The movie that accompanies this report bears out this contention.

It is therefore, my strong recommendation that the ship models used in the visual simulator simply be modeled to the waterline and have priority over the ocean surface. This has been shown to be entirely realistic and eliminates the need for complex modeling and use of additional moving objects for more "proper" occulting.

4.0 CONCLUSION

Two important digital visual techniques became evident during the course of this study. The first was the real-time data base manipulation procedure which was used for producing a realistic dynamic bow wake without resorting to the use of moving objects. The second was the separation of the object list in the data base so that separate sun vectors for each set of objects could be outputted to the image processor. In the latter case, the appearance of dynamic sea state resulted from the use of a constantly changing sun vector and a randomly modeled blue checkerboard. The results of the application of these two techniques are an indication of the kinds of visual effects that remain to be implemented on digital visual systems with little more than imagination.

Both of the techniques used can be considered successful because little additional data base is required, few additional edges have to be processed, and only an insignificant amount of real-time is required. In these particular cases, it can be stated that the visual impact of the resulting scene is far greater than the small amount of visual system capacity that it uses. Because the stated objectives of this study were directed toward realistic sea scenes, data base manipulation and programmed sun vector were used solely to produce dynamic bow wake and dynamic sea state respectively. However, the techniques can be used to produce many other visual effects. Face and/or object substitution can be used for solid or semi-opaque dynamic objects that could simulate smoke, helicopter rotor blades, weapons effects, dust, fire, and weather effects. The programmable independent sun vectors can possibly be used for cloud cover, weather, grain fields, and rotor downwash.

5.0 RECOMMENDATIONS

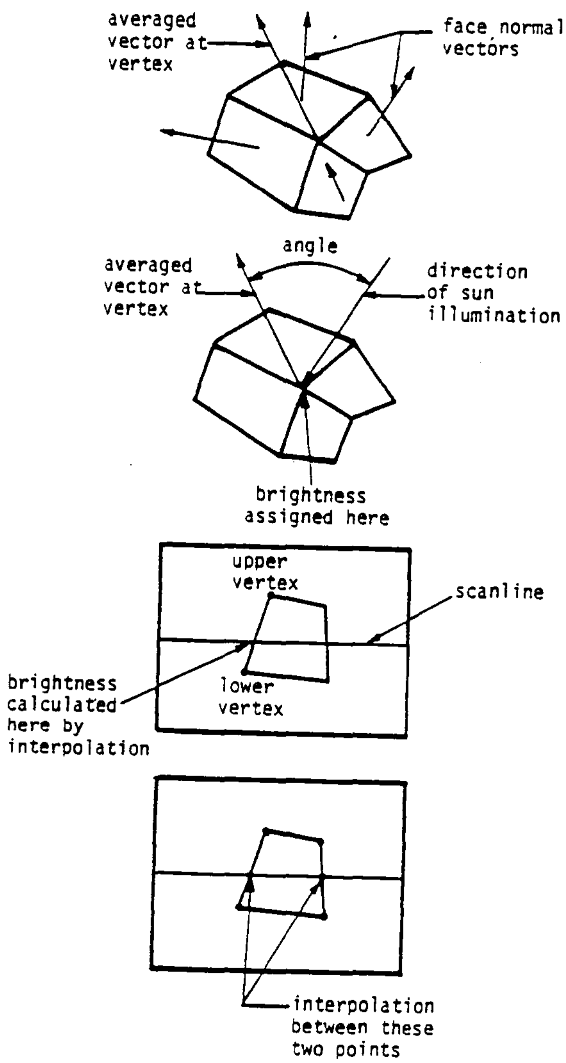
Until recently, digital visual systems were so limited in scene processing capability and real-time processing that the delegation of edges by the user and their movement was limited to the basic training tasks. Usually, these tasks involved runways, taxiways, a few terminal buildings, and in some cases, a single moving object.

The newer visual systems on the other hand, actually have more capability than the user (and sometimes the manufacturer) utilize profitably. In most cases, after the immediate training task is modeled and driven properly, the remainder of the processing is used for "the surrounding area" and "more moving targets". A better approach may be to spend more effort in efficiently utilizing the additional processing to create an overall visual "impression" that may aid in better user acceptance of computer generated imagery. Visual techniques, other than those pursued in this study certainly only await a requirement and some imagination.

APPENDIX I

Smooth Shading

Curved Surface Simulation. A flat-faced object can be made to appear rounded through the application of smooth shading. In this technique, the first step is the construction of vectors at right angles to the flat faces. These "normal vectors" apply to whole faces, so that the illumination changes abruptly as the scanline crosses from one face to the next. To make the variation smooth, the normal vectors for a group of adjacent faces are averaged to produce a vector that points in a direction median to the others. This vector is placed at the vertex where those faces join one another, and becomes known as a "vertex normal". The angle between this vector and the line to the sun is then computed, and an intensity calculated from the cosine of the angle - except that now the brightness is assigned to the vertex rather than a whole face.

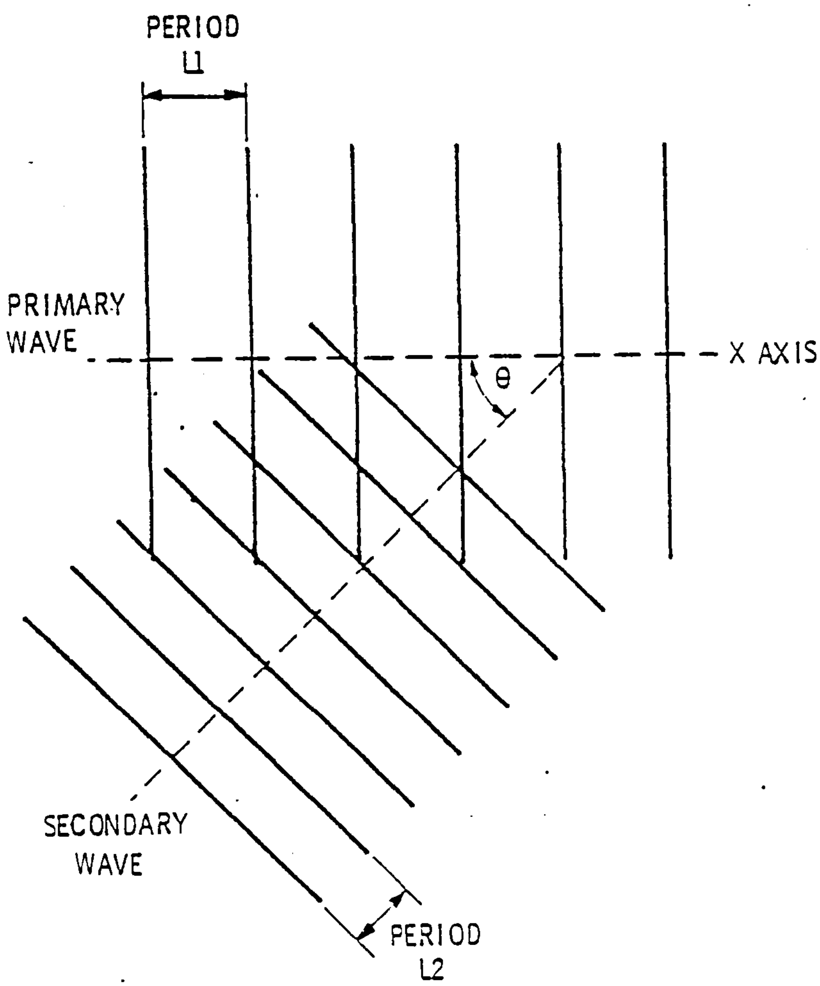


The next step occurs after the projection of the vertices to the picture plane. As a scanline passes through the picture, cutting through a display edge, a brightness value at the point where it cuts is computed by interpolating between the brightness values at the upper vertex and the lower vertex of that edge. The same is done for the other edge defining that same face on this scanline; then the system interpolates between those two brightness values along the scanline. The result is a smooth shading which gives the object a rounded appearance, and which realistically changes as the angle of the object with the sun changes.

Smooth shading can also be applied to flat objects to create special effects. Figure 1 shows the methodology for obtaining the appearance of a confused sea. The effect can be achieved by arranging a number of rectangular faces on a flat surface and applying smooth shading. The vertex normals are arranged in a predetermined pattern, then under the influence of the sun shading computations, the faces take on an undulating blue shade. As the sun is rotated in a circular manner (direction of sun illumination changed) the dark areas change to light areas and vice versa. This change in shading is perceived as movement in the surface.

The predetermined pattern for assigning vertex normals, as mentioned above utilizes a simplified equation for computing wave patterns by assuming they are pure sine waves.

Consider two sine waves, one travelling on the X axis and the other at an angle θ to the X axis.



Letting L_1 and L_2 represent the periods of two waves and θ represents the angle between them then for any (X,Y)

$$\text{Let } Z_1 = \sin\left[(\bmod(X,L_1)/L_1)\ 2\pi\right]$$

$$\text{Let } Z_2 = \sin\left[2\pi\ (\bmod(\sin\phi\, Y + \cos\phi\, X,\ L_2)/L_2)\right]$$

$$\text{Let } Z = Z_1 + Z_2$$

Since the limit of the sine function is -1 to +1, then Z will range from -2 to +2. Z can be scaled so that it serves as an index into a table of normals.

Letting

N = size of table
I = entry into table

This table is filled by (for normal I = i + j + k):

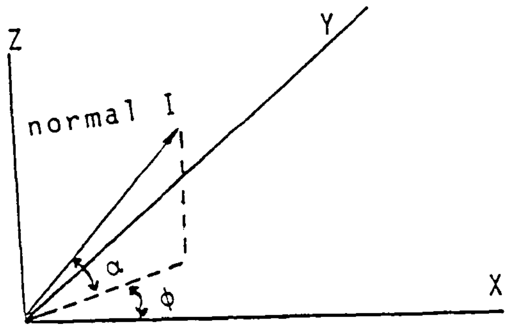
α = predetermined vertical angle

$$\phi = \frac{I}{N} \cdot 2\pi$$

$i = \cos\phi \cos\alpha$

$j = \sin\phi \cos\alpha$

$k = \sin\alpha$



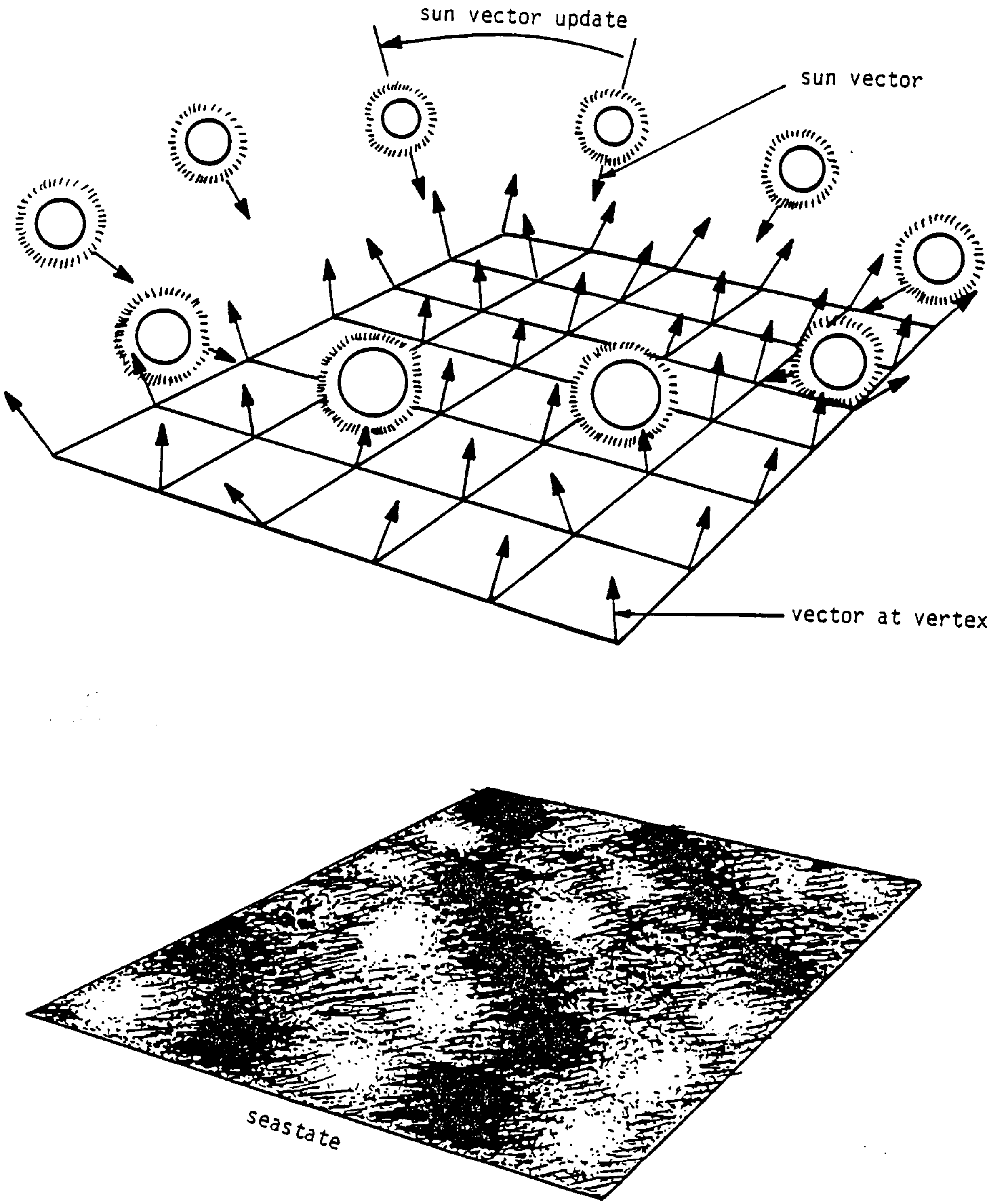


Figure 1 Confused Sea State

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16. Abstract

A Study Contract was awarded to LINK to develop data bases and/or real-time techniques to improve the realism of sea state, bow and stern wake, and ship motion. Experiments would be performed on the LINK Research Visual Simulator in their Sunnyvale Laboratory.

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