

# A MENU-DRIVEN SOFTWARE PACKAGE FOR THE ANIMATION OF OCEAN HYDRODYNAMICS NUMERICAL SIMULATIONS

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## ABSTRACT

Accurate numerical simulation of ocean hydrodynamic processes is complex and difficult, requiring the execution of complicated calculations at high speed using supercomputers. Simulations typically produce values over a grid of points for each of many time intervals. Because this is a dynamic, time-varying process, animation is required to enhance understanding of simulation results. This paper presents a software package which allows the generation of inexpensive, raster-based, computer-generated animation for multi-dimensional hydrodynamic models. The software provides the modeler with the flexibility to view single frames of a proposed animation and to easily modify data normalization and color choice. The final product is a movie produced on a DICOMED graphics film recorder. An animation of a "gravitational collapse" of a cylinder within a density stratified body of water will be discussed as an example.

## 1. INTRODUCTION

Oceanography is undergoing a revolution in terms of the quantities of data which are becoming available for analysis. Satellites are providing detailed data about the ocean's surface. On-site instrumentation now produces multidimensional data, where one dimensional measurements were the recent norm. It is clear that the analytic methods which have been used in the past to study oceanography are no longer sufficient(1); and, if the oceanographic community is to avoid being suffocated in a sea of data, computer graphics must be used to provide a means to visualize these large quantities of data for scientific interpretation and analysis.

Numerical simulations in the physical sciences are modeled efforts which often make complex physical phenomena understandable. The output of a simulation is multi-dimensional data which is then compared with known (measured) realizations of the phenomena of interest. Simulation output usually varies with time; occasionally with other physical parameters. To view the output as merely a sequence of single time frames will, for complex physics such as ocean hydrodynamics, intrinsically limit the understanding of the numerical simulation. Experience indicates that it is just too difficult

to visualize the dynamics of the physics from single time frame output graphics. Many times, sequential contour plots of a process do not allow the richness of the physics to be observed. A color animation, on the other hand, allows us to understand the physical relation of these various phenomena to one another, and frequently points the way to more sophisticated data analysis.

The impetus to merge computer animation and fluid dynamics models has come from both communities. As the computer graphics community has searched, with considerable success, to improve realism, they have found that realism must be based upon sound physical models. Water motions, such as ripples(2) and surface ocean waves(3,4), are a natural scene for such modeling attempts because they are dynamic events which vary over short time periods (unlike, say, mountains or trees). A fluid dynamics model for combining a shear flow with small scale disturbances was used to produce the surface of the planet Jupiter for the movie "2010"(5). Noteworthy is the sheer computer power which went into this effort. Some eight to ten million particles per frame were generated for a 1.4 million pixel texture map, giving an average of about six particles per pixel.

Some recent effort at modeling surface waves have been particularly effective. Fournier and Reeves (6) use a basic Lagrangian model of fluid motion with several special effects added to output scenes of waves breaking against a shoreline. The authors note that their effort omits some phenomena and, indeed, there is of regularity which identifies the output as computer generated. Nonetheless, the pictures are effective portrayals of ocean surface waves and merit viewing both for the quality and the strikingly effective use of color. Mastin et al. (7) utilize a model for the spectrum of fully developed wind seas to model the ocean surface away from the shore.

Thus, computer graphics, in the search for realism, is borrowing models from fluid dynamics while ocean hydrodynamic simulations are using animation to enhance understanding of a model's underlying physics. However, for several reasons these two pursuits will not merge. Computer graphics is searching for visual realism. It is not important to the computer scientist that a physical model of a wave is correct; it is important that a

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viewer of the output picture accepts the product as accurately reflecting the scene as he has perceived it within his experience. The oceanographer, on the other hand, models very complex phenomena and his concern is the physical accuracy of the model. For him, computer animation is only a tool--albeit a valuable one--to understand physical reality.

## 2.0 ANIMATION METHODOLOGY

The goal of this effort, then, is to provide a methodology which allows the creation of inexpensive animations of ocean hydrodynamic simulations. Thus, while the simulations themselves are done on a CRAY XMP computer (a Texas Instruments ASC vectorizing computer was used prior to 1985), it was decided to use Hewlett Packard HP-1000 computer systems for the animation processing. The Ocean Hydrodynamics Branch has several HP-1000 computer systems which are used both as shipboard real-time systems for data collection and for in-house processing. Thus, there is no financial cost associated with using these systems, although the time required for animation processing increases dramatically vis-a-vis the CRAY. A second benefit of working on the HP systems is the availability of a LEXIDATA 3700 (1280 x 1024 resolution with 8 memory planes). The LEXIDATA provides a convenient means of viewing single simulation frames and of performing color selection and animation normalization. A separate program is used to mix colors, in either RGB or HSI (hue-saturation-intensity) space, and output the selection into a color table file which is used in the animation processing.

The simulation results are in scientific units (temperature, density, etc.). Direct color coding of these units will not, in general, produce an effective display because the background will then vary excessively, reducing the visualization of the physics. Thus, these measurements must be normalized in order to effectively animate the fluid dynamics. There is no general procedure to accomplish this animation normalization; this stage of the animation process requires thought and experimentation. For example, in the case of the "gravitational collapse" animation of Section 4, the ocean was density stratified. Direct color coding would produce a striped effect. Accordingly, the data was normalized to remove the density stratification with depth. This produced a uniform background and modified the cylinder (Figure 2a), which was a constant density, to vary relative to the depth. Thus, the waves generated by the gravitational collapse of the cylinder could be easily visualized. This normalization function must be produced on a case-by-case basis for each animation.

Following a simulation on the CRAY, the data is transferred to the HP-1000 using magnetic tape. These tapes are then processed in two stages. At the first stage, the data is normalized as discussed above and colors are selected using several individual frames from the numerical simulation for experimentation. Active areas of the simulation are then examined to determine the frame-to-frame change. If this change is deemed large,

then a time interpolation factor for the DICOMED compatible tapes is calculated. Each pair of frames from the animation are linearly interpolated using the interpolation factor to produce the desired number of additional frames. For example, in the "gravitational collapse" simulation of Section 4, the simulation was calculated on the CRAY at 15 second intervals, but a frame interpolation factor of two was used to obtain an animation frame every 7 1/2 seconds. The output from the first stage is a binary data tape containing entries into the color lookup table for each simulation grid point. This tape is then examined on the LEXIDATA. When the animation is satisfactory, the binary tape is then converted into a DICOMED-compatible formatted magnetic tape (see below). Horizontal and vertical interpolation is performed at this stage to obtain an array of 1K by 1K.

The numerical simulation animations are produced using a DICOMED D48 series graphic film recorder. The DICOMED is a high resolution, multi-purpose film recorder designed to plot vector, raster, and alphanumeric data directly onto black and white or color film. The DICOMED D48 generates color images by multiple exposures through one or more of seven color filters. When a color image is drawn, a "filter wheel" or platter containing seven filters holds a selected colored filter between the CRT and the lens. The DICOMED is available with a wide range of interchangeable optical assemblies and film transports and accommodates a variety of standard film formats and microfiche.

The DICOMED requires input in a specific format and allows the control of the film processing via software control. Plots are processed in either vector or raster modes onto 16 mm, 35 mm, 70 mm, and 105 mm photographic film. The raster mode is used to animate our numerical simulation because the CRAY output for the modeling is already in gridded form. Thus, we avoid the computational and time expense of contouring the simulation output.

In the Raster (Element) Mode each DICOMED image consists of a 4K x 4K array of points plotted at specific exposure levels. A cluster of individual points arranged in a specific order is referred to as an element. An element is made up of a square or rectangular array of one to sixteen points in the horizontal and vertical direction. The number of points in each direction can be independently selected. To avoid colors run together on the film, we use a 2 x 2 element. When processing picture information each point or element may assume one of 256 exposure intensity levels.

Data on the DICOMED-compatible magnetic tape selects the raster mode, element size, spacing between points, spacing between elements, number of points per element and background exposure code. Because physical movement of the DICOMED filter wheel is time consuming, the data is processed in three passes, one for each primary color. Within each of these three passes, the data is packed in a runs encoded format. Runs encoding involves computing the number of consecutive

occurrences of the same intensity of the color being processed and sending this information (rather than the intensities for each pixel) to the DICOMED. When, as is the case in our animations, intensity changes are relatively infrequent, runs encoding results in a very significant compression of the picture images on the DICOMED formatted magnetic tapes. The DICOMED processes these runs encoded files much faster than pixel-by-pixel data, so expense is significantly reduced.

### 3.0 THE MENU SHELL

A menu shell was designed to expedite the process of converting gridded output from numerical simulations into DICOMED formatted magnetic tapes containing the frames for the animation. The menu shell is an easy to use executable interface. Menu choices are organized in a logical, simple block structure. A diagram of the flow of control in the menu shell is shown in Figure 1.

The primary menu is the Main Options Menu. The Main Options Menu allows the film maker to view all current jobs, to modify the job file, to exit the program, or to initiate processing. If no animation normalizing function has been created for the physics of the animation color table, modifications are desired, or the job file needs modification, the film maker selects the Utilities Menu.

The Utilities option displays a menu to change the job file information and create a new color table or normalization file. The Utilities Menu has seven options including returning to the Main Options Menu. The program MixColors interactively produces a new or modified color table. The color table can then be printed and the job file modified. Another option on this menu allows the user to edit and compile a new normalizing function and return to the menu shell. After using this option, the film maker can change the normalizing function in the job file and purge the old normalization file. Selecting return to the Main Options Menu allows the user to select from the Start or Continue Job Menu.

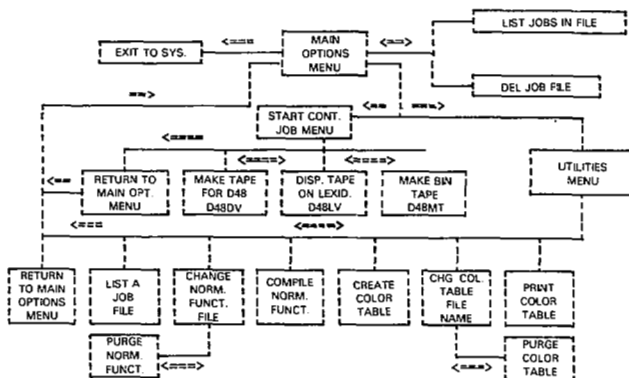


Fig. 1. Control flow diagram for the Menu Shell.

The Start or Continue Job Menu option has three movie making options and the option to return to the main movie making menu. The first option makes the binary tape from the simulation frames and allows interpolation between frames. This option checks the user's job file name and, if it exists, the user is notified and returned to the main options menu. If the job file name doesn't exist, the job name is inserted and program execution continues. After producing the binary tape, the program returns to the menu shell.

The next option on this menu allows the user to view a single frame or a sequence of frames on the Lexidata. If the job file exists, the program checks to see if the animation normalizing function supplied by the user has been compiled. If not, the normalizing function is compiled and written into the normalizing function file. The selected frame is then displayed on the Lexidata, after which the program returns to the start continue job menu.

The last option produces magnetic tapes in DICOMED readable format. The user inputs his job file name. If the job file doesn't exist, the user is notified and returned to the Start or Continue Job Menu. If the job file exists, the program checks to see if the normalization function has been compiled. If necessary, the normalizing function is compiled and written to the normalizing function file. The program then produces a DICOMED compatible tape and returns to the Start Continue Job Menu. The user can now make another animation using the menu shell or exit to the operating system.

### 4.0 SAMPLE SIMULATION (GRAVITATIONAL COLLAPSE)

The numerical simulation of a complicated, three-dimensional, time-dependent phenomenon provides an excellent example of how computer-generated animations prove their worth as diagnostic tools, with an additional value for teaching the experimenter what physics is taking place. The example which we have chosen is the gravitational collapse of a mixed region in an incompressible density-stratified region of the ocean. Complicating factors are that the numerical simulations are performed in cylindrical coordinates on a rotating earth.

The interior of the ocean is a random superposition of internal-inertial waves whose restoring forces are the background stratification and the local Coriolis force. Much as sporadic breaking occurs in ocean surface waves when their amplitudes are increased, so too does breaking occur within the interior of the ocean. This breaking process generates fairly compact, partially-mixed regions with characteristic dimensions of ~2m. An oceanographically relevant question concerns the fate of these partially-mixed regions. That is, what is the evolution and longevity of their

characteristic density and velocity signatures, as well as the nature of the radiated wave field?

This process is modeled in an axisymmetric system, with the equations

$$\begin{aligned} \frac{\partial u}{\partial t} + u \frac{\partial u}{\partial r} + w \frac{\partial u}{\partial z} - f v - \frac{v^2}{r} = \\ - \frac{1}{\rho_0} \frac{\partial P}{\partial r} - K_H \left( \frac{1}{r} \frac{\partial}{\partial r} r \frac{\partial}{\partial r} - \frac{1}{r^2} \right)^2 u \\ + K_V \frac{\partial^2 u}{\partial z^2} \end{aligned} \quad (4.1)$$

$$\begin{aligned} \frac{\partial v}{\partial t} + u \frac{\partial v}{\partial r} + \frac{uv}{r} + f u + w \frac{\partial v}{\partial z} = \\ - K_H \left( \frac{1}{r} \frac{\partial}{\partial r} r \frac{\partial}{\partial r} - \frac{1}{r^2} \right)^2 v \\ + K_V \frac{\partial^2 v}{\partial z^2} \end{aligned} \quad (4.2)$$

$$0 = - \frac{1}{\rho_0} \frac{\partial P}{\partial z} + b \quad (4.3)$$

$$\begin{aligned} \frac{\partial b}{\partial t} + u \frac{\partial b}{\partial r} + \frac{\partial b}{\partial z} = \\ - K_H \left( \frac{1}{r} \frac{\partial}{\partial r} r \frac{\partial b}{\partial r} \right)^2 \\ + K_V \frac{\partial^2 b}{\partial z^2} \end{aligned} \quad (4.4)$$

$$\frac{1}{r} \frac{\partial ru}{\partial r} + \frac{\partial w}{\partial z} = 0 \quad (4.5)$$

where  $P$ ,  $b$ ,  $u$ ,  $v$ , and  $w$  are the pressure, buoyancy, and the radial, azimuthal, and vertical velocity components. The buoyancy  $b = -g(\rho - \rho_0)/\rho_0$ ,  $\rho = \rho(r, z, t)$  and  $\rho_0$  is the constant reference (Boussinesq) density. Note that axisymmetry implies  $\partial/\partial\theta = 0$  and that we have assumed a hydrostatic balance in the vertical. That is, equ.

(4.3) does not contain vertical accelerations, but assumes instead a balance between the buoyancy and pressure gradient forces. For the first half Brunt-Vaisala period or so, we expect that the effects of these vertical accelerations may be important. For the remainder of the simulation however, the important accelerations are primarily horizontal, and we expect the simulation to be representative.

We assume that, initially, the mixed region is cylindrically shaped with a radius and height of 2.5 m and 5.0 m respectively. We have enlarged these values over naturally occurring ones to enhance the visual effect. This initial configuration is shown in Fig. 2a where we portray the initial buoyancy field. This fluid within the mixed region is taken to be homogeneous and the exterior fluid has a Brunt-Vaisala frequency of  $4 \cdot 10^{-3} \text{ s}^{-1}$  or a period of 26.2 min. The Coriolis parameter  $f = 7.27 \cdot 10^{-5} \text{ s}^{-1}$  and the diffusion constants are  $K_H = 6.25 \cdot 10^3 \text{ cm}^4 \text{ s}^{-1}$  and  $K_V = 1 \text{ cm}^2 \text{ s}^{-1}$ . As the homogeneous region collapses under the effect of gravity, several things happen. First of all, it gets thinner and spreads laterally. As it does so, the collapsing region radiates internal waves and two classes of these may be seen in the ensuing evolution (Figs. 2b-2h): the guided modes and the plane waves.

The first class to appear is the wave guide modes. The guided wave which first emerges is the second mode, which manifests itself as two vertically-arranged buoyancy extrema (one maximum and one minimum) which propagate to the right. Toward the very end of the simulation, the slower propagating fourth mode (two buoyancy maxima and two minima) appear and also propagate to the right. Between the emergence of the second and fourth guided modes, the plane internal waves emerge in the form of rays. These are the inclined regions which emanate from the collapsing region. The highest frequency waves propagate away most rapidly and these are arrayed at the largest angle to the horizontal (e.g., Fig. 2c). As the collapse progresses, the lower frequency waves emerge, and these are evidenced by the rays assuming a smaller angle to the horizontal (e.g., Fig. 2h).

The numerical simulation shown in Fig. 2 is a very complicated process with several phenomena taking place simultaneously. Animation significantly enhanced understanding of the wave types discussed above.

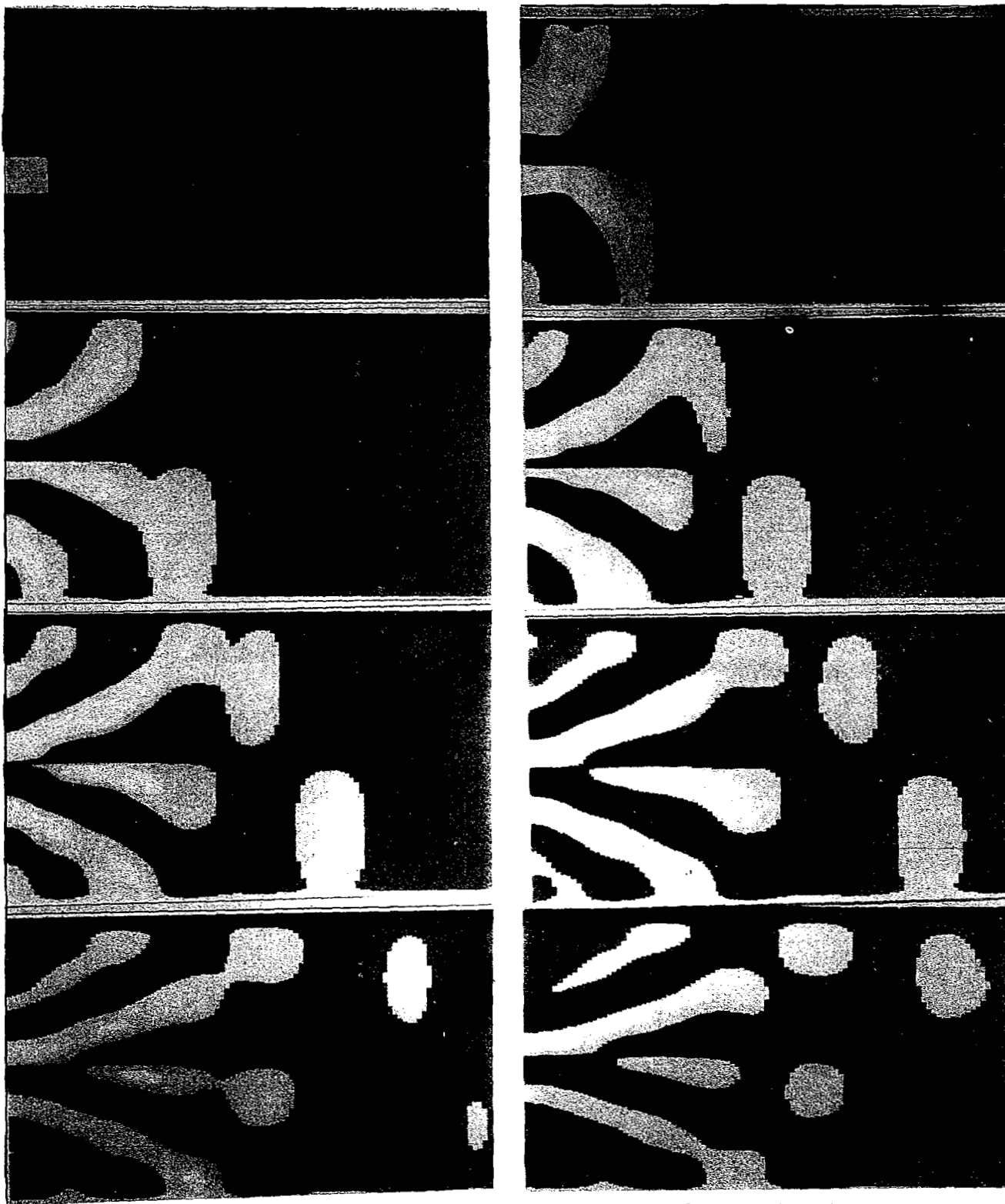


Fig. 2. Eight frames from the "gravity collapse" animation. Figure 2a shows the initial condition ( $t = 0$  min.). Figures 2b-2h are the animation frames at  $t = 5, 10, \dots, 35$  min., respectively. In the animation, the background is light blue. Four successfullly darker shades of blue are for the water which is denser than background; blue-green, green, yellow and red are used for water which is less dense than background. 480 frames were calculated, at  $7 \frac{1}{2}$  second intervals, and each reproduced three times on film to obtain a one minute animation.

## 5.0 ALTERNATIVE TECHNOLOGIES

Although constantly improved, the graphics film recorder is a decade-old technology. A newer technology is the direct copy to videotape of the output of a bit-mapped RGB (red-green-blue) display terminal. These converters combine animation controllers with sync generators to turn high line rate RGB video output into video tape recorder (VTR) compatible RS170 RGB and/or NTSC video. The converters can be operated under computer control and will access each frame on a numbered, frame-by-frame basis. Thus, the computer generates a single frame on the display device which, on completion, is then automatically sent to the video tape recorder. Such systems have existed for several years for low-to-medium resolution graphics but have only just recently become available for high resolution (1280 x 1024) monitors(8). For low resolution, the technical difficulty (and expense) is primarily the precision required to align the frames precisely. The new high resolution systems additionally require data compression and anti-aliasing algorithms. The cost of such a system, including a high quality (3/4", 1", or U-matic) VTR, is about \$25,000.

Although not a graphical output device, optical discs offer the potential to store large amounts of data. A one minute, high resolution animation can be stored on a pixel-by-pixel basis in 1.5 gigabytes at the 24 frames per second used by 16 mm film. Obviously, the use of data compression techniques would increase, usually very significantly, the number of stored frames. Storage of an entire animation on disc would allow easy viewing of any frame on a random access basis and would reduce the effort needed to produce DICOMED compatible tapes.

## 6.0 SUMMARY

This paper has presented a software package which simplifies the process of animating scientific numerical simulations. The design criteria for the animation package was to minimize production costs and to provide an animation menu shell which would guide the scientist through the animation process, with a minimum of interaction required. The animation process requires only that the scientist or animator generate an animation normalization function and an appropriate color table. The remainder of the processing is controlled by a menu shell, which leads the animator through the steps required to produce the animation. The "gravitational collapse" simulation illustrates the use of animation to the process of understanding the physical relation of complex phenomena.

## REFERENCES

- (1) Munk, W.H., 1986. Introductory Remarks, The Fourth Working Symposium on Oceanographic Data Systems (IEEE), Scripps Institution of Oceanography, San Diego, CA, Feb. 4-6.
- (2) Kajiya, J.T., et al., 1985. "Trees," ACM SIGGRAPH Video Review, Issue 23.
- (3) Max, N.L., 1981, "Vector procedural models for natural terrain: waves and islands in the sunset," SIGGRAPH 81 Conference Proceedings, 317-324.
- (4) Peachey, D.R., 1986. "Modeling waves and surf," SIGGRAPH 86 Conference Proceedings, 187-201.
- (5) Yaeger, L. and C. Upson, 1986. "Combining physical and visual simulation--creation of the planet Jupiter for the film 2010," SIGGRAPH 86 Conference Proceedings, 85-93.
- (6) Fournier, A. and W.T. Reeves, 1986. "A simple model of ocean waves," SIGGRAPH 86 Conference Proceedings, 75-84.
- (7) Mastin, G.A., P.A. Watterberg and J.F. Mareda, 1987. "Fourier synthesis of ocean scenes," IEEE Computer Graphics and Applications, 7-3, 16-23.
- (8) Wilson, A., 1986. "Converters put high-resolution images on tape," Digital Design (Dec.), 27.

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