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EnSight Volume Visualization

by Richard C. Angelini

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14. ABSTRACT Volume visualization is a computationally intensive image-rendering technique that has been around since the 1970s; however, the advent of modern parallel computing architecture and high-speed graphics cards now makes this technique an attractive alternative to traditional surface-based methods. The resulting image using the volume visualization algorithm can best be described as an opaque cloud of data that allow the viewer to see millions or billions of computational values simultaneously. There are numerous algorithms available to perform volume rendering, and this report focuses on a specific implementation developed by Computational Engineering, Inc.—the developers of EnSight, which is a commonly used general-purpose visualization package used at the U.S. Army Research Laboratory (ARL). EnSight provides an extendable graphical user interface that supports client-server access to data calculated on high-performance computing systems supported by ARL and the Department of Defense. The volume-rendering technique implemented by EnSight was applied to ARL datasets, and the methodology and results are presented in this report.			
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Contents

List of Figures

Acknowledgments

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1. Introduction

Volume visualization is a technique used in scientific visualization and computer-based imaging to represent an entire volume of data in such a way as to allow for complex physical phenomena to be clearly displayed. The resulting image can best be described as an opaque cloud of data that utilizes a color scale to represent values within the computational mesh. The ability to manipulate and animate this volume "cloud" over time provides insight into a large three-dimensional dataset and allows the viewer to see the results of millions (or billions) of computational values simultaneously. Volume visualization allows the analyst to view an entire range of values within a computational domain rather than calculate a specific scalar value for an isosurface or a range of values on a simple two-dimensional clip plane. By adjusting minimum and maximum data ranges and through the judicious use of color opacity, analysts can make complex physical phenomena clearly visible within the rendered volume.

There are many algorithms available to perform volume rendering, including volume ray casting, splatting, shear warp, texture mapping, and various hardware-accelerated rendering techniques. It is not the purpose of this report to describe or evaluate these various techniques, as they are well documented in numerous published papers (Drebin et al., 1988; Howison et al., 2012; Kaufman, 1991; Wittenbrink, 1998). However, the availability of the current generation of high-performance parallel computing systems and fast graphics processors allows these various techniques to excel in a variety of implementations.

Volume visualization concepts have existed since the 1970s and emerged in the 1990s as a key field of visualization, computer graphics, and computer imaging (Kaufman, 1991). Volume rendering was applied initially to medical imaging, and most of the early implementations were application specific, not general purpose in nature. Since that time, the algorithms have evolved to be more general purpose, and mature open-source visualization applications, such as ParaView and VisIt, have included volume-rendering capabilities for many years, implementing techniques and algorithms developed primarily for the large Department of Energy research laboratories. However, initial efforts to use these open-source general-purpose applications for volume visualization of data typically generated at the U.S. Army Research Laboratory (ARL) was limited either by file format, data size, or computational resources, and the results were marginally successful at best.

2. Methodology

Since the early 1990s, ARL has been using the commercial software package EnSight from Computational Engineering International (CEI) as a general-purpose visualization package. Computational scientists within ARL currently use EnSight, in conjunction with ParaView and VisIt, for high-performance scientific visualization. EnSight has been a valuable tool for post-processing computational results and has been effective at providing general-purpose visualization across a number of computational disciplines at ARL. Most of the visualization techniques in EnSight use points, lines, and surfaces to represent data, requiring volumetric data to be subsampled in some way (EnSight, 2012). Traditionally, analysts would rely on clip planes, contour plots, isosurfaces, isovolumes, and particle traces (figure 1) to extract information from their computational mesh. These techniques allow analysts to view a specific value or small range of values within their dataset and, in most cases, animate those results over time. Certain aspects of the calculation are visible using these techniques, and the results are effective for a concise range of values.

Volume rendering was first introduced in EnSight in 2010, and the initial implementation was a computationally expensive process. The ability to generate volumes was tied directly to the performance and memory of a local graphics video card. This hardware-accelerated unstructured volume renderer used a hybrid raycasting system that decomposed the geometry into tetrahedra and pushed that representation directly to the graphics card (Frank, 2011). Performance of this algorithm varied directly with the size of the computational mesh, the size of the image being rendered, and the complexity of the scene, but the overriding implementation issue was the amount of memory required on the local graphics card to render the image. Because of the size of datasets typically generated at ARL, it turned out that this method was not practical for any real-world datasets, including computational results typically addressed at ARL.

In 2012, EnSight 10.0 introduced a new volume-rendering technique. This updated technique maintains the original technique that was dependent on exclusive use of the graphics card but with a significantly improved algorithm. However, this method continued to be too limiting for general-purpose use. Fortunately, EnSight implemented a second algorithm that uses a structured grid to remap the computational mesh. This second method allows the end user to resample the data to any resolution by creating an underlying structured volume based on values provided by the analyst. Based on positive performance results obtained on initial testing of large datasets generated at ARL, this methodology is very efficient, and EnSight is able to better leverage the computational resources with a structured volume algorithm. The volume calculated is less precise than the original hardware-based rendering methodology but faster and more flexible in terms of end user interactive response. Despite the reduced accuracy of the calculated volume, there is often little to no perceivable difference in the rendering results.
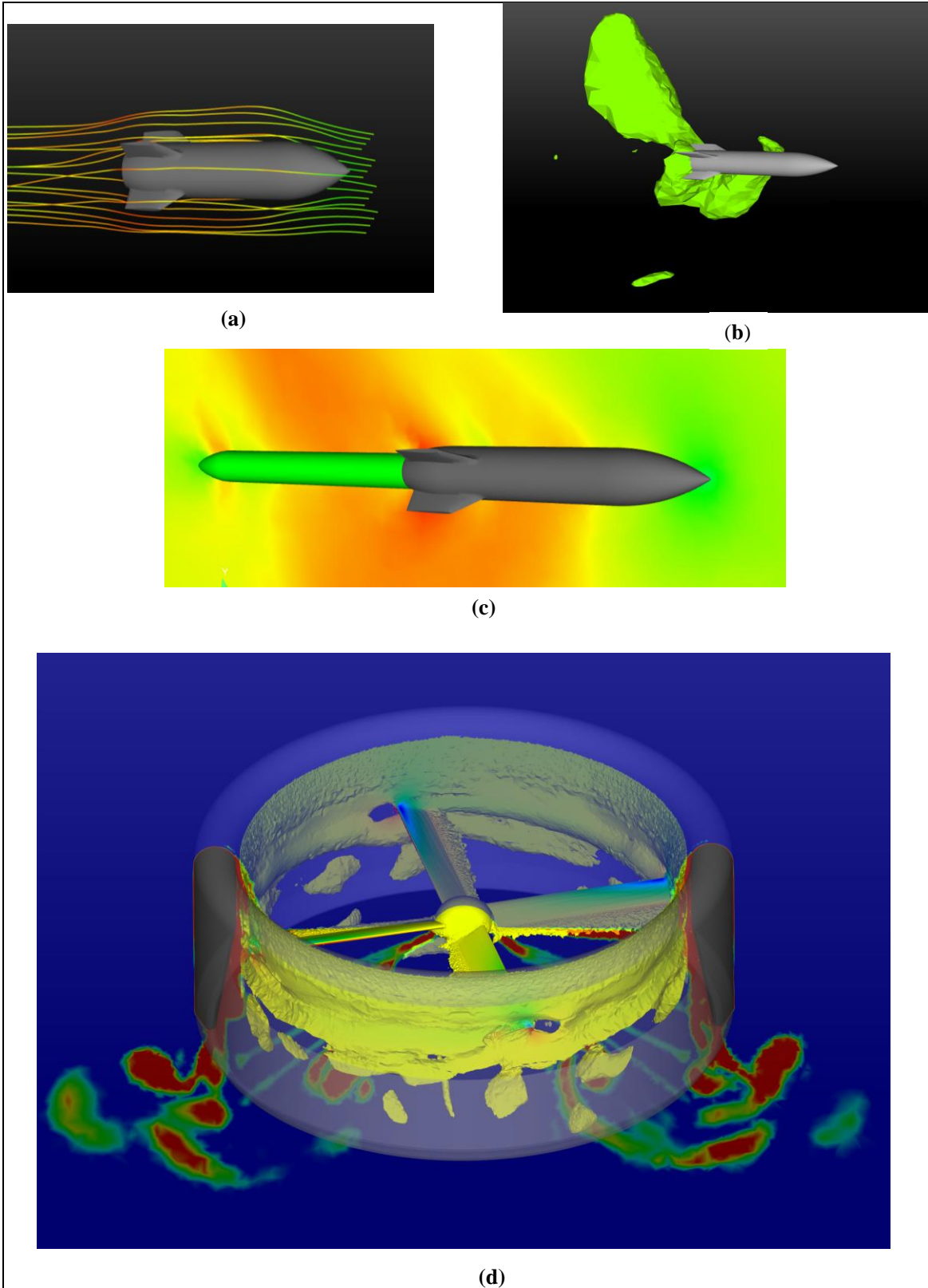
(a)

(b)

(c)

(d)

Figure 1. Traditional visualization techniques: (a) particle trace, (b) cutting plane, (c) isosurface, and (d) clip plane and isosurface applied to ducted rotor dataset.

This new methodology also allows the analyst to subset the dataset using a bounding box, therefore focusing the volume-rendering algorithm to a specific area of interest. This methodology is important from a computational standpoint—the volume-rendering algorithms are computationally expensive, as they must look at every cell within the mesh multiple times. By subsetting the dataset, analysts are able to significantly reduce the amount of computational effort required to calculate the volume rendering. Additionally, when a structured grid is resampled from unstructured data, the sample is focused on the region of interest rather than the entire computational mesh, therefore reducing the computational effort by reducing the number of cells included in the volume calculation. Subsetting the volume is limited by a specific rectangular area oriented in any direction and by identifying a specific variable to be volume rendered. EnSight will volume render that variable within the defined bounding box area (Grimsrud, 2012).

Volume rendering was successfully tested using both a traditional client-server connection between the desktop workstation and the ARL utility server as well as the HPCMP-provided secure remote desktop (SRD) application. When a traditional client-server connection is used with EnSight, the volume renderer depends on the local graphics hardware on the desktop workstation to display the volume. When volume animations are created in batch, the EnSight volume renderer requires the use of the ARL utility server, specifically the back-end graphics nodes, as the rendering algorithm still relies on the availability of graphics hardware. (The volume renderer cannot be used on traditional compute nodes that do not have graphics hardware.) A sample EnSight command file and Portable Batch System (PBS) batch script used for creating a volume animation are included in the appendix of this report.

From an end user perspective, during early exploration of the dataset, a very low-resolution (such as $32 \times 32 \times 32$) structured mesh can be used to get general characteristics of the data in the selected region. As the analyst begins to manipulate the color palette to extract features of interest, the resolution of the structured mesh can be increased to show more detail. Previewing the volume using lower-resolution structured mesh will show individual planes used in the volume-rendering technique. As the resolution of the structured mesh is increased, the details of the mesh become visually insignificant. The results of changing the resolution of the structured mesh are demonstrated in figure 2. The lower-resolution images visibly demonstrate how the data has been subsampled using a structured mesh. As the resolution of the structured mesh increases, the result volume rendering becomes more precise, features become more sharply defined, and the visual artifacts of the subsampling disappear.

Early testing of the algorithm indicates that a final resolution of 200^3 for the subsampling mesh seems to be sufficient for creating video animations, and a resolution of 500^3 provides high enough resolution for printed renderings of the dataset. These values may ultimately be dataset dependent, and additional use of this algorithm will further refine these "rules of thumb" values.

(a) $16 \times 16 \times 16$ structured mesh

(b) $32 \times 32 \times 32$ structured mesh

(c) $64 \times 64 \times 64$ structured mesh

(d) $100 \times 100 \times 100$ structured mesh

(e) $250 \times 250 \times 250$ structured mesh

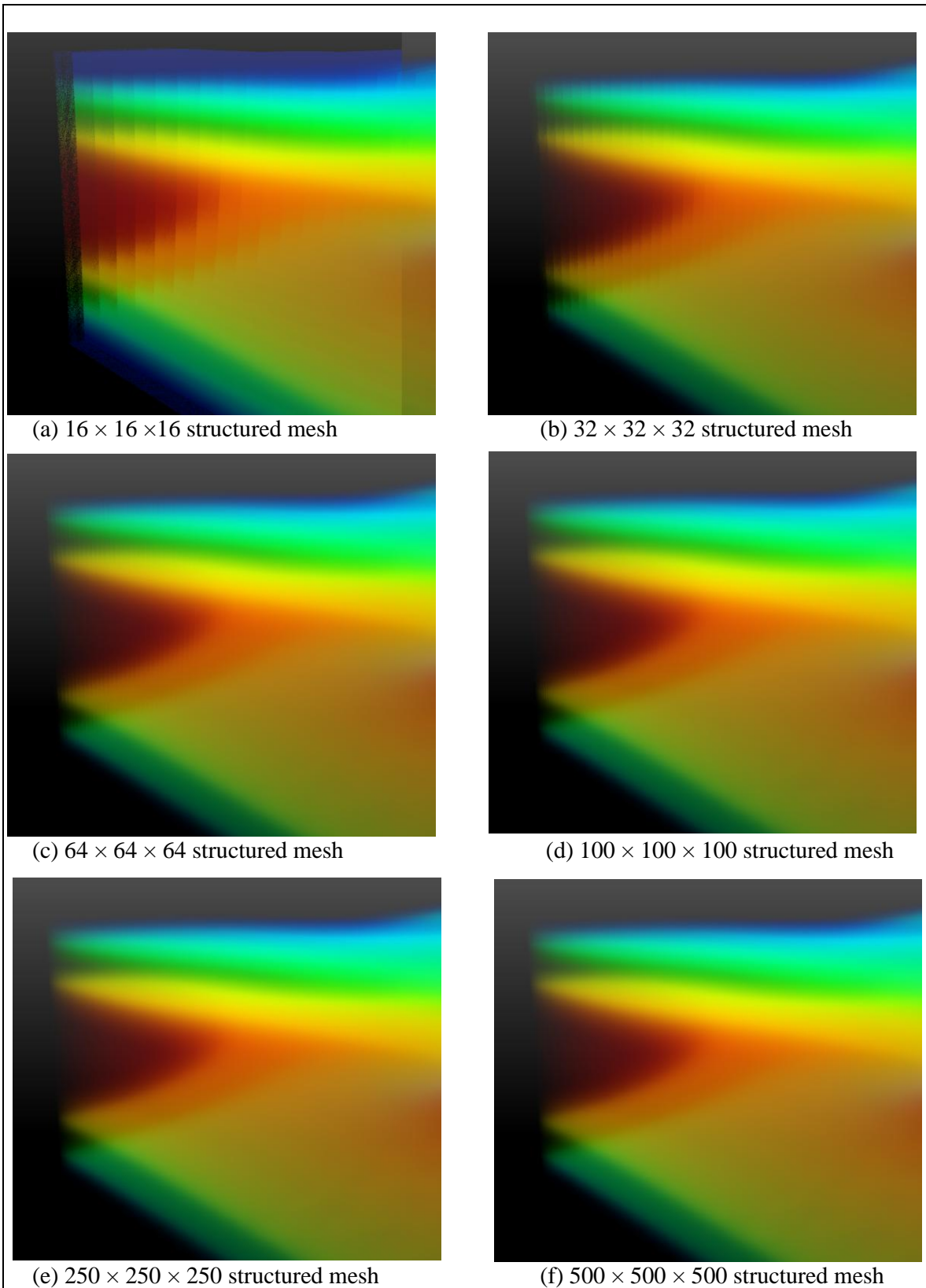(f) $500 \times 500 \times 500$ structured mesh

Figure 2. Result of changing the resolution of the resampled volume data using a structured mesh.

This volume-rendering technique allows the analyst to view an entire volume of data at once, without having to slice the data in any way. The process involves finding all cells that overlap each pixel and accumulating a color for that pixel from the color and transparency of each cell. Volumes can be constant colored, but more often the analyst will color the volume using a palette corresponding to a variable or a variable component. Color palettes include transparency ("alpha") values, allowing control of transparency based on variable value (EnSight, 2012).

3. Case Study

The ARL Data Analysis and Assessment Center (DAAC) team, part of the ARL Department of Defense Supercomputing Resource Center (DSRC), took this opportunity to demonstrate the new volume-rendering techniques made available in EnSight 10.0 to the research community at ARL. Because of the complexity and limitations experienced with previous volume visualization implementations, the customer base at ARL had not been exposed to this technique. ARL visualization experts had limited experience and success with previous volume-rendering efforts and wanted to explore the value of EnSight's implementation as applied to real-world datasets. In an effort to demonstrate the use of volume rendering to the ARL EnSight user community, an example of volume rendering was developed and compared to traditional isosurface rendering techniques and presented to potential users (figure 3). This sample volume rendering generated interest from the user community, and several datasets were evaluated for potential application of volume rendering.

Of particular interest was a computational fluid dynamics dataset of a ducted rotor. This time-dependent dataset demonstrates how volume rendering can show the dynamic physics associated with a spinning vehicle rotor. Specifically, this simulation represents a ducted rotor in hover, and these rotors would be used for small unmanned aerial vehicles. This particular simulation is being used to study the effect of tip clearance on the performance of the rotor in hover. The volume visualization clearly shows the transient flow field as the rotor starts spinning and how the quiescent fluid is disturbed as the rotor spins up and reaches a quasi-steady (periodic) state (Dinavahi, 2012). This dataset allowed the EnSight volume-rendering features to be fully exercised and used most of the features required to create a successful volume:

- Subsetting the data using the box tool to highlight a specific region within the computational mesh.

- Resampling an unstructured dataset using a three-dimensional structured mesh within the region of interest.

- Judicious editing of the opacity/intensity levels of the color palette to extract detail from the volume rendering.
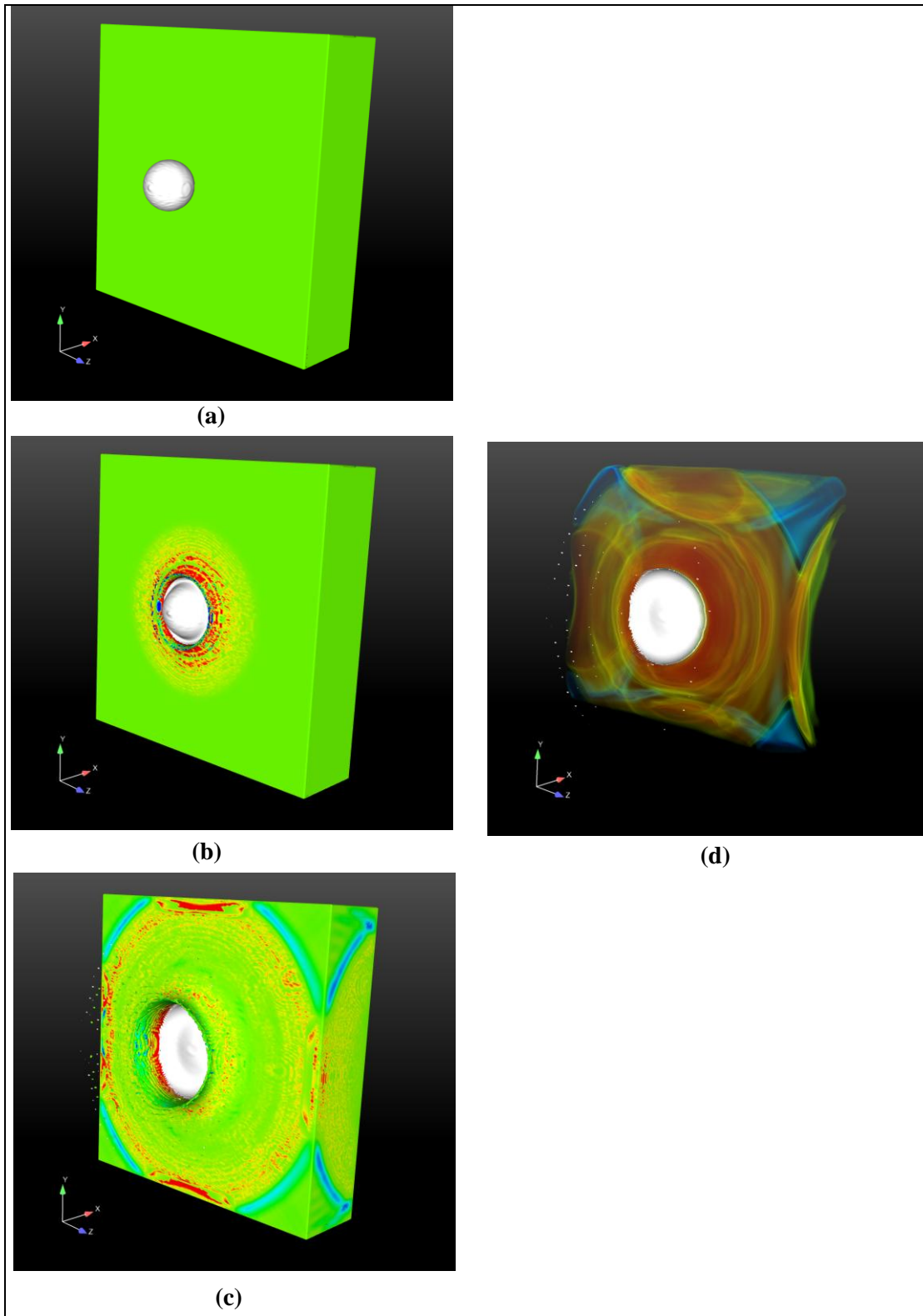
(a)

(b)

(d)

(c)

Figure 3. Comparing traditional visualization results to volume-rendered results: (a–c) shows a traditional isosurface visualization of a time-dependent dataset, and (d) demonstrates how volume visualization can be used to depict the data in such a way as to see the entire volume, not just the surface data.

7

Displaying a part or parts in EnSight as a volume-rendered object is accomplished via EnSight's "part element representations" feature. Parts are generally loaded into EnSight by default in Border, Feature Angle, or Full representation. These representations include only point, line, or surface data. The "volume" element representation will activate volume rendering for a part. Just as for surfaces, the part color dialog can be used to control the color and opacity of the volume. The volume can be colored by a scalar, vector, or vector component, and the colors will be assigned based on the palette (EnSight, 2012). Figure 4 shows how to represent an EnSight part as a volume through the EnSight graphical user interface (GUI).

The method for refining the results from the volume rendering is described in this next critical step. EnSight allows for advanced control of volume rendering by providing a mechanism to adjust the magnitude of the variable palette and by adjusting the alpha value. The alpha value is the opacity/intensity of the particular computational variable when volume rendered. This means that variable levels within the volume rendering can be emphasized by specifically increasing the alpha magnitude of these select levels (EnSight, 2012). Conversely, specific values can be removed from the volume by adjusting the alpha magnitude to zero. For instance, there may be a variable that represents a common value such as "air" that the analyst wants to remove from the volume. By selecting the range of scalar values that represent air and setting the opacity to zero, the analyst removes the "air" from the volume, allowing the volume renderer to focus on other critical values.

The analyst can also scale up the entire alpha by adjusting a multiplier value in the palette editor's "Options" tab. The analyst can also achieve sharp delineations in the rendered volume by adjusting the variable palette using a "sawtooth" pattern. Creating very abrupt changes in the opacity/intensity value at the correct value within the scalar variable range will result in a sharp peak in the representation of that data point in the volume image. The default color palette does not highlight the detail available within the volume. By carefully selecting values with the scalar range to highlight, the analyst can visually emphasize critical elements of the calculation. This technique is represented in figure 5. In figure 5a, a bounding box is created to subsample the computation mesh to the area of interest. The volume-rendered results are then displayed (5b) based on the default color palette values. Figure 5c shows the color palette editors with default values for opacity/intensity and the min/max variable values, and 5d displays the adjusted palette with the min/max range of the UVW variable adjusted and the opacity/intensity values adjusted. The final image in figure 5e emphasizes the complex fluid disturbances.
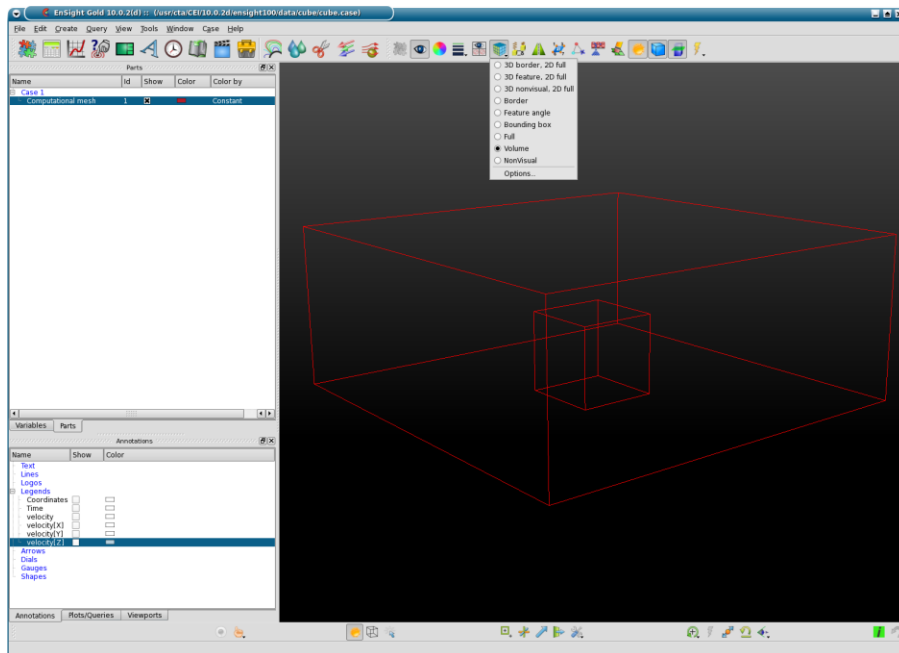
(a) From the feature bar of the main window of the EnSight GUI, select the parent part (the part that is to be displayed as a volume), and using the "part element representation" icon, change the object to be displayed as a volume.
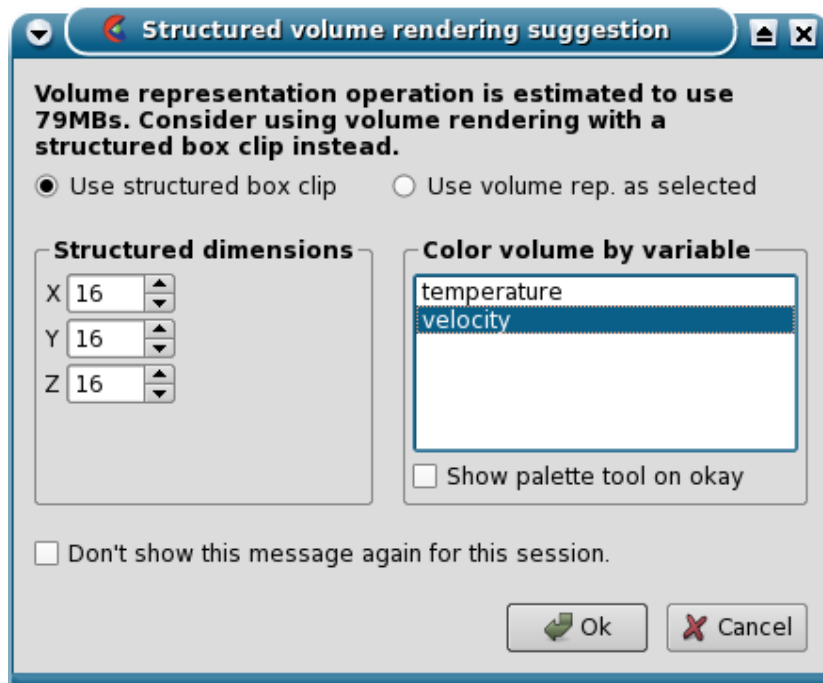
(b) After changing the element representation to be "volume", use a structured clip box to create the volume, define the size of the three-dimensional structured clip used to subsample the dataset, and select the variable to be used to generate the volume.

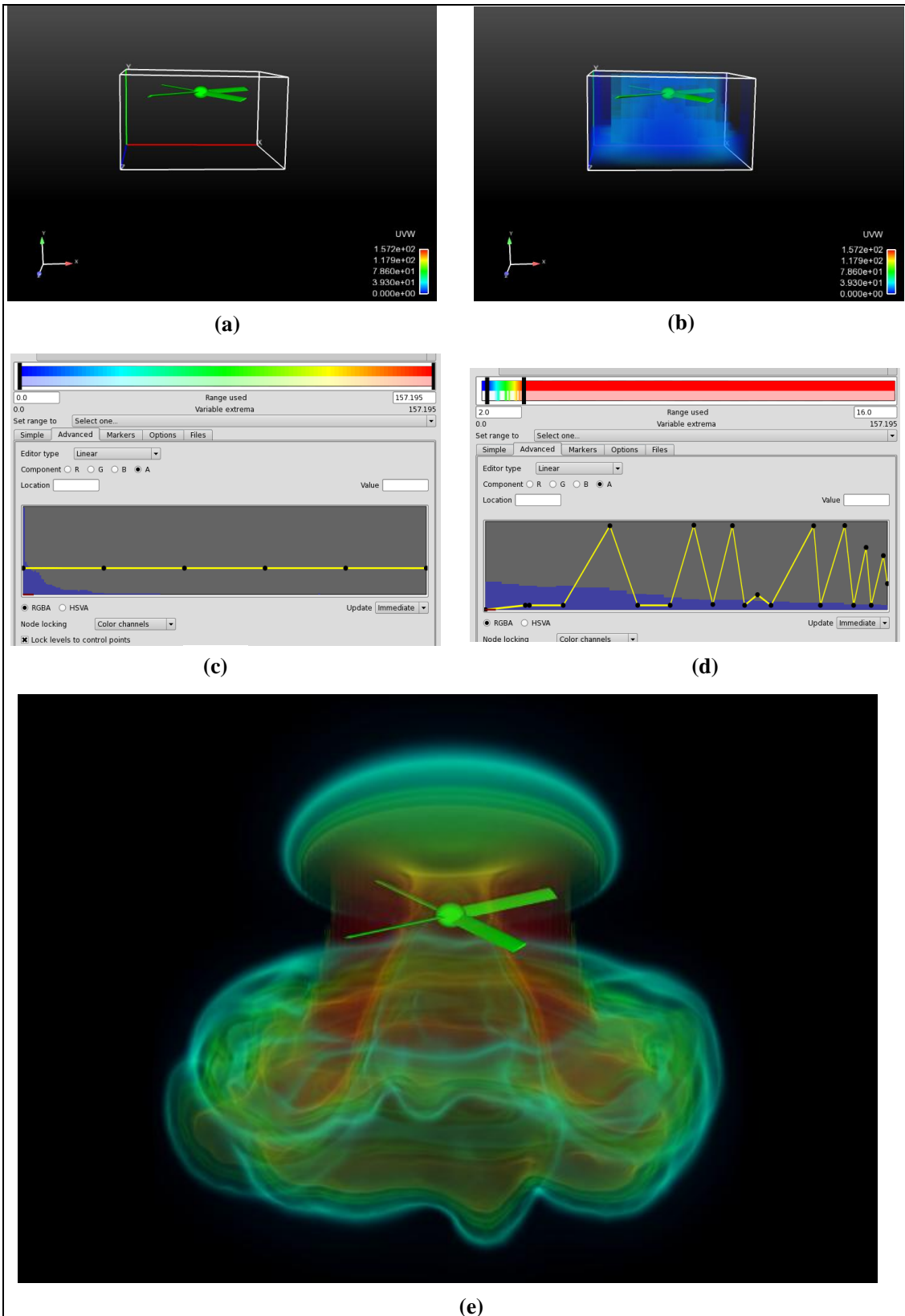Figure 4. How to display an EnSight part as a volume via the GUI.

Figure 5. Using the EnSight palette editor to extract details from the volume.

4. Conclusion

Volume visualization provides additional insight into the analysis of large three-dimensional datasets. Traditional visualization techniques, such as clip planes and isosurfaces, depend on looking at a subset of the calculated data and representing those results on the surface of the geometric object. Volume rendering allows millions (or billions) of calculated values to be displayed simultaneously. Through judicious adjustments to the color palette opacity and intensity levels, enormous amounts of information can be extracted for an entire volume of data. The volume-rendering technique implemented in EnSight provides the end user with an easy-to-use interface and an efficient algorithm to either quickly display low-resolution representations of the volume or generate very high-resolution (yet computationally expensive) volume images. By using a bounding box to select the region of interest within the computational mesh, the analyst can focus the volume-rendering algorithm on a specific portion of the mesh, therefore saving valuable computational time. The use of a structured mesh to subset the data provides a reasonable approximation of the values within the domain, and the ability to manipulate the resolution of the resampled data allows the analyst to refine the rendering to extract valuable features from the data that would not have previously been available using traditional rendering techniques. Real-time volume rendering has matured to the point where it can become a powerful tool in the ARL researcher's interactive analytical toolkit.

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Appendix. Sample EnSight Batch Command File and Portable Batch System (PBS) Script

The EnSight Batch Command File "sample.enc" was developed for the Department of Defense/High-Performance Computing Modernization Program utility server located at the U.S. Army Research Laboratory.

```
VERSION 10.02

# Restore EnSight context file
file: restore_context Vorticity_Magnitude.ctx
#

# Select the volume part and change density of structured volume mesh (2003)
part: select_begin
 19
part: select_end
part: modify_begin
clip: sample_step 200 200 200
part: modify_end

#
anim_recorders: render_offscreen ON
file: image_numpasses 4
file: image_stereo current
file: image_screen_tiling 1 1

# set output file name
file: animation_file vortmag_notext

# set output image dimensions
file: animation_window_size user_defined
file: animation_window_xy 1600 1200

file: animation_frames 170
file: animation_multiple_images OFF
file: animation_play_flipbook OFF
file: animation_play_time ON
file: animation_play_keyframe OFF
file: animation_reset_flipbook OFF
file: animation_reset_traces OFF
file: animation_reset_time ON
file: animation_reset_keyframe OFF
```

file: save_animation

PBS Batch Script

```csh
#!/bin/csh -f

#PBS -A ARLAP123456
#PBS -N VortBatch
#PBS -q vnc
#PBS -l walltime=36:00:00
#PBS -l select=1:mpiprocs=16:ncpus=16:ngpus=1
#PBS -l place=scatter:excl
#PBS -l application=ensight

# initialize modules environment and load default ensight module

source /app/modules/init/csh
module load ensight
module list

cd ~angel/Surya

setenv ENSIGHT10_MAX_CTHREADS 16
setenv ENSIGHT10_MAX_SOSTHREADS 16
setenv ENSIGHT10_MAX_THREADS 16

echo HOSTNAME= `hostname -s`

# Set up working directory ${CENTER}/batch

if (! -d ${CENTER}/batch) mkdir ${CENTER}/batch
cp VortMag2/VortMag_NoText.ctx* ${CENTER}/batch
cp VortMag2/notext.enc ${CENTER}/batch
cd ${CENTER}/batch

# Run Ensight, using the notext.enc EnSight command file as input

env DISPLAY=:0.0 /app/VirtualGL/bin/vglrun ensight100 -batch -gold -no_start_screen \
-c  localhost -p sample.enc
```

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