Graphic Interface for the Efficient Postprocessing of Huge Simulation Data

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Introduction

As the size of the computer simulations is being increased, postprocessing of the enormous data created by such simulations becomes a key factor for the analysis of the data. Simple graph plots or contour plots were used frequently in old days (and they are still very useful), but new tools become required with the growth of the data size. Fortunately, development of computers accelerates the development of graphic representation of the data both from hardware and software view points. With the graphic representation, important features of the data can be easily understood and it helps our understanding the contents of the data through visualized images.

Currently, strongest tools for the postprocessing of the enormous data are graphic workstations. They have special graphic board with which manipulation of the graphic images can be done quickly under the interactive environment. Besides, they have good user interface mostly using graphics(GUI). Such interface helps users to learn how to use visualization software used for the postprocessing of the data.

In fluid dynamics, visualization has been one of the important analysis tools for many years. T. V. Karman found so called "Karman vortex" through the flow visualization study and O. Reynolds used the visualization of the flow inside a pipe to study the transition from laminar to turbulent flows. The motion of fluids can never be seen without some techniques. Therefore, flow visualization is still now one of the important research fields in fluid dynamics. The same is true for computational fluid dynamics. With increase of the data, we start recognizing the importance of the development of flow visualizations as a postprocess of the computer simulations.

Now, there are many commercial software available for the computational flow visualization. However, most of them focus on showing nice color graphics and do not consider importance of analyzing the data. In the present paper, visualization software and its graphic interface are discussed. Emphasis is laid on the software for the research rather than for presenting nice pictures.

Purpose of the Postprocessing

Visualized data obtained by the postprocessing can be used for many different purposes, but they can be categorized into two parts. One is to use the visualized images to explain the contents of the data. For instance, visualized images are used in the presentation at the conference to explain the nature of the simulated data, or used in the presentation to persuade top managers to pay attention to new ideas and give large amount of budget. This type of usage is called "presentation graphics". When presentation graphics are used, the person using the visualized images knows in advance what should be drawn to explain what he wants to say. Such visualized images should be created usually by a sophisticated rendering to make it easy for non-specialists to understand it. Nice and beautiful pictures are attractive for this. The process to create such images may take long time, which does not matter in "presentation graphics".

The other is called "research graphics". In research graphics, most emphasized point is good response that is necessary for the researchers to deduce underlying physics hiding in the data. Mostly, sophisticated images are (of course useful, but) not as important as quick response. Low quality images may be better than sophisticated images if obtained quickly. Suppose it takes two days to obtain nice pictures that use sophisticated renderings, it would not be useful for the research.

In the present paper, only the second purpose is focused on. In other words, we seek for the required functionalities of the visualization for the research.

Research Graphics

In the case of a fluid dynamics simulation (the research field is usually called Computational Fluid Dynamics:CFD), computations should be conducted for a large region to avoid the numerical disturbance at the outer boundary. Besides, the accuracy of the solution simply depends on the number of the computational grid points used for the simulation and large number of the grid points are necessarily distributed, which create large amount of resultant data. However, in most of the cases, important physical phenomenon occurs only near the body surface and thus main interest is focused there. For instance, when the aerodynamic forces acting on the body is only the interest, most of the data away from the body becomes useless in this particular analysis. When the vortices behind the body are of the main interest, no-vorticity regions are not necessarily processed. In other words, most of the data are necessary only for the reliability and the accuracy for the computations but are obstructive or at least not useful for the analysis. Thus the postprocess has the task to eliminate these tedious data and to highlight the feature of the flow fields.

Graphics, which include many features of graphical representations such as graph plots, contour plots, etc., help the researchers to reduce their work for the huge simulation data and make analysis. In other words, the graphics work as an interface through which the researchers can access the huge simulation data.

Figure 1 is a typical process to analyze the simulation data using graphics. In the case of CFD, the $x-y-z$ coordinates and the flow variables (density, velocity vector, etc.) at every grid points are stored in the files and they are first read in the postprocess program. The number of the grid points ranges from thousands to more than a million at one time step. Sometimes the flow fields are time-dependent and then the data size becomes enormous. As visualized images are just two-dimensional, the whole three-dimensional time-dependent flow fields cannot be shown at once. Thus a portion of the flow fields should be selected and cut out and visualized. The body surfaces, the grid surfaces, $x-$, $y-$, $z-$planes, etc. can be candidates. The contours of various flow functions (density, pressure, Mach number, etc.) are to be plotted on these surfaces. When analyzing the data, we may want to plot several functions at the same time. We may want to compare the same function plots for the different result files to compare them. Therefore, the surfaces and the functions should be easily changeable by a certain interface having a quick response. There are two choice for the interface. One is a menu palette and the other is a command input. Most of the commercial software uses menu palettes because the menus can easily restrict the variety of the user inputs and avoid the unexpected inputs which may cause some errors. The command input, on the other hand, is more flexible to control the process but is more difficult to use. Advanced users of these software often prefer the flexibility of the command inputs unless the menu palettes would be carefully designed to satisfy the researchers who would like to visualize the data as simply and as straightforward as possible. The disadvantage of the command input is that the users may type many keys. Preparing default values may relieve this load, although the choice of proper values require the knowledge of the research fields.

The visualized images are displayed on a window rather than a full-screen of a display in the case of workstations. Multiwindows for the graphics help the researchers in many different ways. Figures 2(a) and (b) show some examples. Two windows in Fig. 2 (a) show two computed flow fields around the same body. Two images are shown on the workstation screen at the same time. The comparison is easily made. Figure 2 (b) shows a close-up view of the image as well as the whole image. The white square in the whole image corresponds to the close-up area. Many of the commercial software have the capability to zoom images but only in one window and therefore it becomes difficult to imagine the location of the close-up area in a whole field once the image is zoomed up.

The quality of the graphics from the viewpoint of Computer Graphics(CG) is not important for the research. In computer graphics, shading and/or lighting are used to make the images to be realistic. In the research graphics, they are necessary only to show the shape of the surfaces , as shown in Fig. 3. No more advanced shading models are required in general.

In Fig. 1, there are many arrows which indicate the paths of the process. The users plot and delete graphics, change flow functions, change viewing parameters and change data. These processes are not determined in advance and any paths indicated by arrows should be allowed in the software. A good software should be designed to allow the users to choose any paths directly.

Finally when finishing the process, the history of the process or the current state of the process should be stored in a file for the restart. If the contents of the file are simple texts, modification is easy and similar images with different data can be quickly obtained.

How do we reduce the workload for huge output data? Contour line plots and contour surface plots show a scalar function distribution on a specified surface. By selecting the proper surfaces, the feature of the flow field can be recognized. However, the limitation of the number of surfaces does exist because the surface behind the other one cannot be seen. Figure 4 shows the total-pressure contour plots over a delta wing. Three surfaces would be the limit even with the semi-transparent technique. To increase the number of surfaces to be plotted, "thresholding" is effective. Thresholding is a technique to cut out some part of the contour surfaces when the value of a scalar function (not necessarily the same as the function for the contour plots) becomes out of the specified range. In the case of the delta wing in Fig. 4, only the region where the total-pressure value is lower than that of uniform flow is concerned. Hence the region where the total-pressure is higher than the value of the uniform flow is cut out as shown in Fig. 5 where fourteen surfaces are plotted without any significant overlaps. Thresholding does not only increase the number of the surfaces plotted, but highlights a key phenomenon of the flow field. Over a delta wing, a pair of vortices are generated from the apex of the wing and the vortices govern the aerodynamic characteristics of the wing. Lower total-pressure indicates the location of the vortices and Figure 5 is much more helpful than Fig. 4.

Another visualization method to highlight the feature of flow fields is "iso-surface" plots. Iso-surface is a surface where a scalar function value is uniform. Figure 6 shows iso-surfaces where the streamwise velocity is zero over the delta wing. In this case, the iso-surfaces are closed and the streamwise velocity are negative inside the surfaces. Negative velocity suggests an important phenomenon of the "vortex breakdown". Iso-surface is a useful visualization method to indicate specific regions.

In the case of CFD, there is a special technique to show the flow feature, known as "particle tracing" or "streamline tracing" which shows the path of a fluid particle as a curved line or a set of dots. A numerical integration is necessary to obtain a streamline and the accuracy of tracing critically affects the trace of the streamline.[2] Figure 7 shows streamlines over the delta wing. The vortex breakdown (reversed flow) is clearly observed over the rear portion of the wing.

As discussed above, the graphic use as a postprocessing of the data has many different features from that for general computer graphics where realistic images are pursued.

Requirements for the Software and the Hardwares

This section summarizes the requirements for the software and hardwares to realize the graphics environment for the research.

As discussed previously, the research graphics software would be the center core of the system. Three-dimensional CG, not necessarily being of high-quality, had better be natively supported, or a graphics engine should be attached so that researchers can use graphics without feeling any stresses. Even though all the data are neither necessary nor loaded on the memory, a certain amount of core memory is also required. For example, 64MB or more is preferable for the data of half million grid points, which is a common size for the current three-dimensional simulations in CFD. As well as the graphics performance, the CPU performance is important since the postprocess includes various kinds of computations, such as the calculations of the flow functions, cutting with arbitrary planes, tracing particles, and so on.

These requirements are satisfied on many graphics workstations and some kinds of powerful personal computers. Most of the commercial software for the visualization run only on the graphics workstations currently. However the situation will be changed soon because of the progress of the personal computers.

When the data are time-dependent, an animation of the visualized images often helps our understanding the computed results. Two kinds of animations are possible. One is a video animation which is made by frame-by-frame recording of the time-sequence of the images. Special hardwares, such as a frame-by-frame video recorder, a video controller, TV signal generator (usually a frame buffer) are necessary. The other is a "real-time" animation which animates the images on a computer display. This requires much more CPU / graphics performance than the video animations though its response and flexibility much helps the analysis. Some of the recent graphic workstations, with their improved capability of CPU power, supply us the free software that creates "animation on the screen" with a little effort. Users simply prepare a sequence of the image files in the specified format. Animation on the screen is a very useful tool especially for the unsteady flow research and will be used by many researchers in the future. In general, several system configurations are possible for creating animations and thorough discussions can be found in Ref. 3.

Advanced Visualization Methods -feature probe

For well-trained researchers, the features previously shown in this paper are sufficient for their research on the huge simulation data. When CFD becomes an engineering tool and many people start using CFD simulations just as a tool for the analysis, the software may need one more capability. The same is true when the data is too large and the researchers cannot imagine what to plot or where to look at. Here, "feature probe" is required. Feature probe is an intelligent system that tells the user what to do. The software, with its intelligent feature, can specify the region where important physical phenomenon happens or specify the functions that should be plotted on the screen. One simple example is a singularity in the flow field. In the example used in the previous section, negative streamwise velocity region shows the reversal flow region where "vortex breakdown" occurs. Mathematical operations to check the singularity of the velocity field would tell us the location of the stagnation point where vortex breakdown starts. If the software tells us the location of the singularity, we can release particles from that point to find the hiding physics. The same is true for another functions. If we apply this to the surface of the body, we can easily find the line of the flow separation.

With the feature probe, researchers can focus on the region that should be analyzed. Feature probe can eliminate the region which can be discarded for the research and saves the data size for the analysis. However, we have to be careful because we might miss an important phenomenon if the software miss it. Developing low-level feature probe is easy but sophisticated one should be carefully designed and made.

Summary

The research graphics handling huge simulation data were discussed. In the case of the Computational Fluid Dynamics, all of the computed data are not necessary for the analysis and it is important for the postprocessing software to reduce the size of the data and to help researchers to extract the key features of the computed flow fields. User interface should be prepared so that the researchers can be used naturally. Menu-driven structure is not necessarily good for the research graphics. In conclusion, a good postprocessing software does not only have the functions to show the required images but also have researcher-friendly interfaces, which allow the researchers to do many types of postprocessings in flexible manner.

References

1. Buning, P. G. and Steger, J. L., "Graphics and Flow Visualization in Computational Fluid Dynamics," AIAA Paper 85-1507-CP, July 1985.
2. Tamura, Y. and Fujii, K., "Visualization for Computational Fluid Dynamics and the Comparison with Experiments," AIAA Paper 90-3031-CP, August 1990.

3. Yoshiaki Tamura and Kozo Fujii, "Visualization of Computed Data for Unsteady Flow Simulations," the third Asian Symposium on Visualization (ASV '94 Chiba), Chiba, Japan, May 16-20, 1994, pp. 874-879.

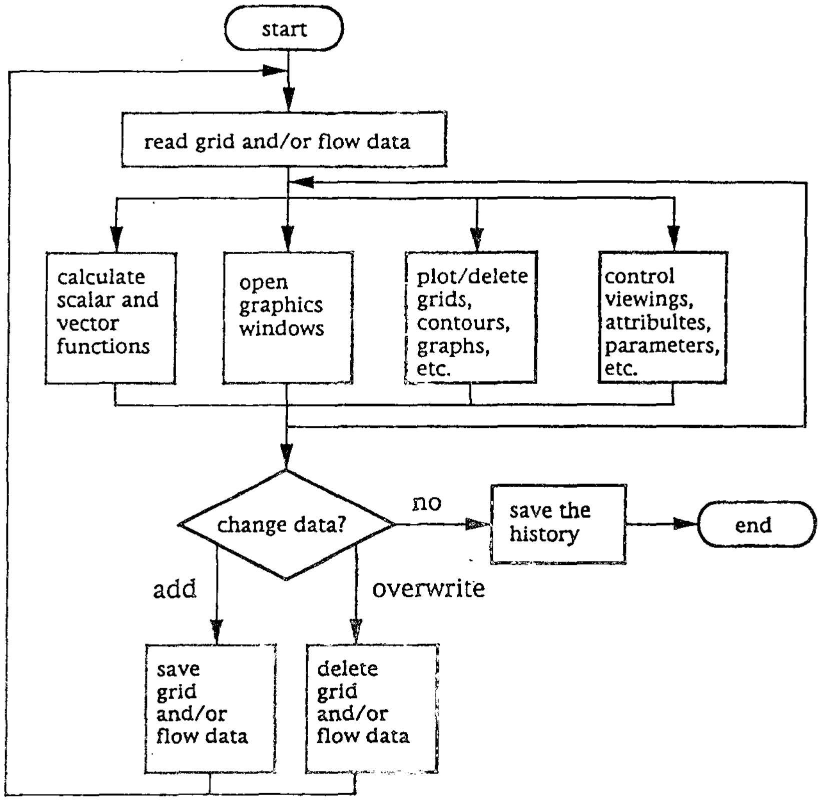
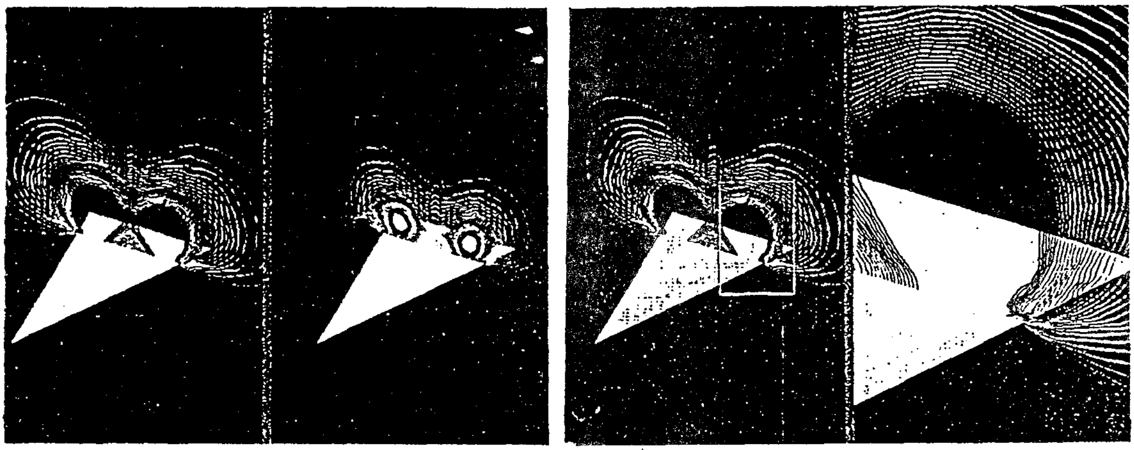


Figure 1 Typical postprocess of computed flow fields.



(a) Two windows to compare two results. (b) A Close-up window.

Figure 2 Multiwindows for analysis.

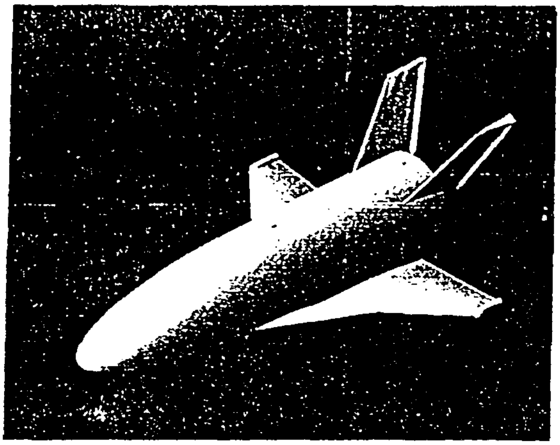


Figure 3 Shaded image of a spacecraft.

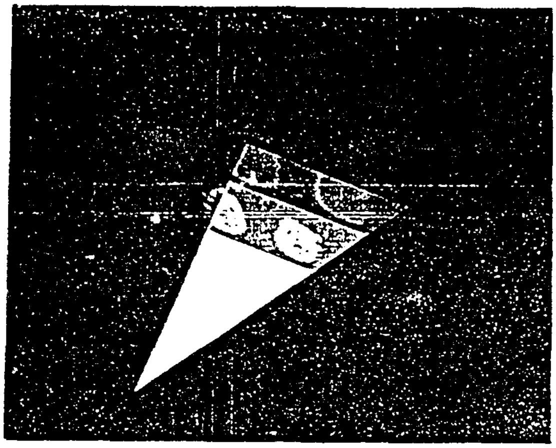


Figure 4 Semi-transparent contour surface plots.

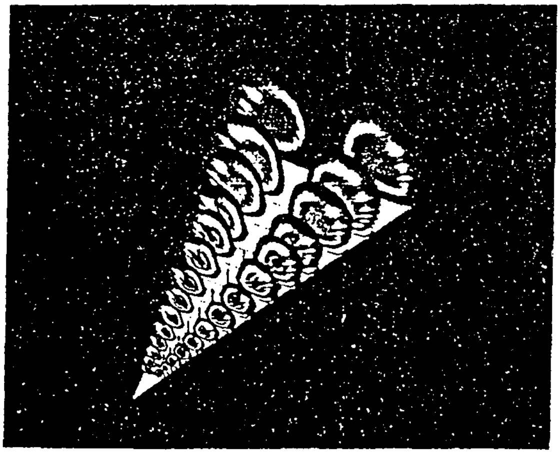


Figure 5 Contour surface plots with thresholding.

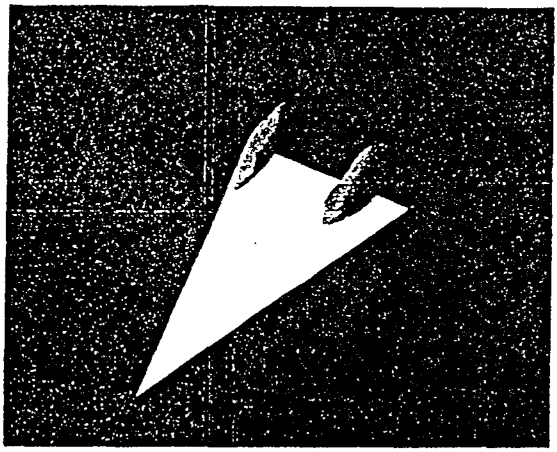


Figure 6 Iso-surface plots indicating reversed flows.

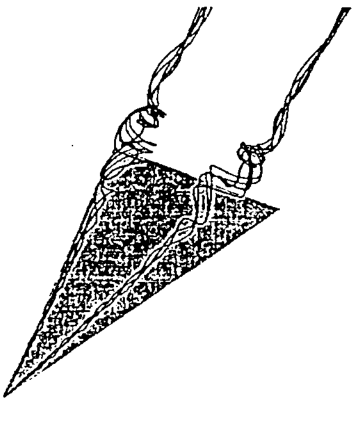


Figure 7 Streamlines over the delta wing.