Benefits of Immersion for Viewing 3D Data

Alexander Barrie
Aerospace Engineering
abarrie@vt.edu

Bradley Cassell
Computer Science
brcassel@vt.edu

Matthew Cooper
Computer Science
macooper@vt.edu

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Abstract

Immersion has been shown to be beneficial in a number of different application domains. We attempted to quantify the effect of immersion on 3D abstract data analysis. We developed a program to show users animated plasma flows in a CAVE [1] environment. Stereopsis and field of regard were varied in a user test involving flows around a sphere. Our results showed that the stereopsis helped users to better understand the flow and retain more information, and also decreased the time taken to learn how to use the system. The increased field of regard resulted in shorter overall times taken to comprehend the flows. Users generally liked the immersive environment compared to more typical desktop interfaces, however the low immersion setups had some trouble navigating.

1 Introduction

As computers become more powerful, they are able to simulate more complex situations. Many of these situations that are now becoming available are complicated to the point where they are difficult to understand using a standard 2D interface such as a desktop computer. For large scale, complex data sets, it is necessary to come up with a better method for viewing and comprehending results. The best simulation in the world is no good if there is not an adequate way to interpret the results.

We have tested the idea of viewing complex 3D data sets in an immersive environment in the CAVE at Virginia Tech [1]. We designed a program that shows the user of series charged particle flows around a charged sphere and asks them to rank the flows in order of various aerodynamics characteristics. Stereo vision and field of regard were varied between subjects to help define which components of immersion help to view large and confusing data sets. It was our theory that stereo vision and a large field of regard would help users to better visualize 3D data, such as charged particle flows.

2 Related Work

2.1 Immersion

Raja and his colleagues found that highly immersive environments were more useful for performing tasks in a virtual environment [2] than environments with little immersion. We wanted to confirm this in the specific case of complex 3D scientific data by testing field of regard and stereopsis as specific immersive measures. In another paper, Bowman discussed how to present the user with a large amount of information [3]. The correlation between abstract and perceptual information was also discussed. We have tried to use some of these techniques to display a large amount of information to the user in such a way that they were easily able to view and absorb the important aspects of the information presented.

2.2 Flows

Fuhrmann and Gröller discuss 3D flow visualization and suggest methods for evenly distributing the streamlines of a flow [4], which was considered as a means for distributing the visualized streamlines in our case. Forsberg and colleagues discuss visualizing arterial flow in a four wall CAVE [5] like VT's. Their study was based on standard fluid flows, whereas we used more complicated charged particle plasma streams. Their realization that stereopsis played a crucial role in users' understanding was an important building block for our study. Craig [6] developed a CAVE based visualization system. They discuss some of the challenges and potential solutions for visualizing flows in a 3D immersive environment. All of these systems were for viewing uniform flows. Our system deals with charged particle flows that vary in density, potential, temperature, etc. resulting in a more complex visualization process as more data can be presented to the user. Brieda [7] developed an immersive system specifically designed for visualizing plasmas, but the system was not animated and could only be viewed as a still object.

3 Program Design

Our program was designed to work in a variety of environments that utilize 3D data. This allows for easy modification for the running of future experiments involving many different types of scientific or other data. Our program was written in DIVERSE [8], using data from Coliseum [9], and visualized in the VT CAVE [1].

3.1 DIVERSE

Experimentalists rarely have a CAVE available with which to view data, so this project was developed specifically to be compiled and run anywhere. Therefore, for compatibility purposes, DIVERSE (Device Independent Virtual Environments: Reconfigurable, Scalable, Extensible) was used as the development language. DIVERSE handles shared memory, tracker input and data processing, and display internally. This allows code written in DIVERSE to be run on almost any configuration, from a desktop to an HMD to the CAVE. Almost any type of input can also be accommodated. DIVERSE also has a built-in interface to Performer which was also used. This allows the easy addition of models, primitives, lighting, etc, to better show and understand the portrayed data. DIVERSE also allows for basic network support allowing for multiple users to view the data in future versions [8, 10].

3.2 CAVE

Our experiment was conducted in the Virginia Tech CAVE. The CAVE is a four walled (front, left, right, floor) immersive environment capable of displaying stereo images to the user with head tracking. Control for starting and stopping the experiment was performed by a desktop computer off to the side. The subject controlled his position and orientation with a six DOF wand with a thumbstick [1]. A standard flying transportation technique was used [11]. While the CAVE was used for this experiment, the results should be similar for any method of increasing field of regard or adding stereopsis, such as an HMD [11], or iDesk [11].

3.3 Coliseum

Coliseum is a package for simulating electric plume interactions currently being developed by Virginia Tech, MIT, and the Air Force Research Lab. This package is useful for modeling flows from various forms of electric propulsion and their interactions with objects. The program accepts a wide range of inputs, including multiple source streams, models, and a variety of different solvers. Our tests utilized charged ion flows moving past a charged sphere. These flows were calculated using the DRACO DADI field solver, a component of Coliseum [9].

3.4 Program

Our basic program reads in a data file generated by Coliseum [9] in Tecplot format [12]. The file contains a three dimensional grid of information. Each grid space corresponds to a volume of 3D space. Objects can then be inserted at arbitrary points into this grid and manipulated according to the local values. For example, our experiment read in average velocity data from the file and charged particles were inserted into the domain and moved according to the velocity field. As a particle moved from one grid space into the next, its velocity would be updated along a new vector. Other objects can also be placed in the experimental domain as a reference. In our case, a large sphere was placed in the particle stream since the data modeled flow around a sphere. The program was intentionally designed to allow for expansion and has freedom to test many different situations and types of data for future experiments.

4 Experiment

4.1 Experimental Design

In the aerospace community, fluid flows have always been difficult to visualize.

Charged particle flows even more so, since there are many more quantities of interest. Standard visualization programs such as Tecplot [12] are based on PC interaction. They have no real method for the user to see the interior of flows and focus mainly on the surface characteristics. Interior views are made by making cuts in the volume to expose a new surface. Animations are also difficult to view since the user cannot easily make these cuts or modify the view parameters while the animation is running. These charged particle flows were therefore chosen as a good testbed for immersive animated data visualization.

Our experiment exposed the subject to three charged particle flows around a sphere. The first flow was a neutral flow with perfectly straight streamlines. The second flow was a positively charged flow moving past a positively charged sphere, resulting in the particles being repulsed by the sphere. The third flow was a positive flow moving past a negative sphere resulting in attraction toward the sphere. All three flows had the sphere sticking out of the side of the flow facing the subjects initial position. This forced the user to navigate around the flow somewhat in order to get more useful views of the flow. The most divergent flow, which was shown to the subjects second, is shown in Figure 1.

Subjects were given a demographic survey beforehand and were given time to familiarize with the controls and environment by navigating around a submarine model. Subjects were instructed to look at each flow and pay attention to speed, shape, and behavior around the sphere. They were told to take as much time as they needed to fully understand the flow, but to finish as quickly as possible. Afterwards, the subjects were given an objective survey asking them to rank the flows in order of divergence, velocity, turbulence, and flow separation around the sphere. Further explanation of these terms can be found in Karamcheti [13]. They were then given a more subjective survey of what helped them or hindered them in understanding the flows and what they would change about the simulation to make it better.

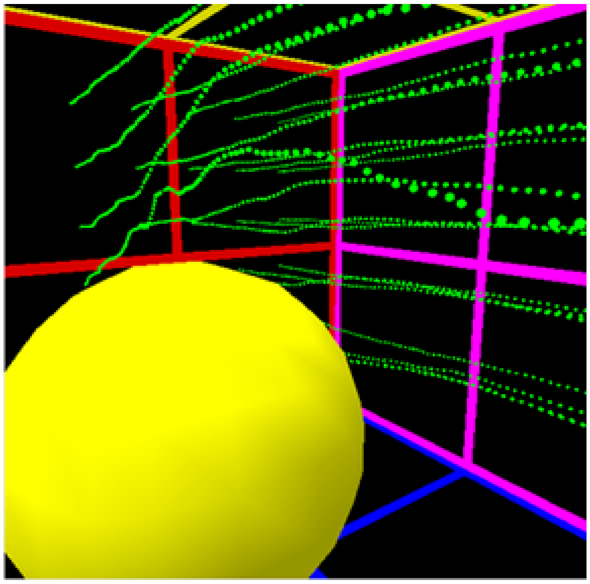

Figure 1: View of the four walled CAVE simulator and the flow past a sphere that a subject would see

4.2 Preliminary Study

For our preliminary study we had four users run through our experiment: three men and one woman. Two of the men were aerospace graduate students, the other was an undergraduate. The one woman was an ocean engineer. We found that the two aerospace graduate students were able to get all of the questions on the survey correct, while the undergraduate and the ocean engineer had more difficulty. This implied that domain knowledge was an important factor in the understanding of the data. We therefore decided that it would be best for our formal study if we limited our subjects to aerospace engineering students.

4.3 Formal Study

We expanded the number of subjects used for our formal study from four to 24, 22 men and two women. All of our subjects were aerospace engineers. This gave us 6 subjects for each of the different independent variables situations we were testing. A description of these and our conclusions follow.

4.4 Independent/Dependent Variables

We had two independent variables that we tested: stereopsis and field of regard. This allowed us to have four different configurations in which to test subjects; no stereopsis and one wall of the CAVE, no stereopsis and four walls of the CAVE, stereopsis and one wall of the CAVE, and stereopsis and four walls of the CAVE. Each subject saw the three flows in only one of these configurations.

For our dependent variables, we recorded the time it took each subject to become familiar with each of the four flows, as well as the time it took them to fill out the survey afterwards.

5 Results and Discussion

5.1 Formal Results

5.1.1 Times

There was a clear learning effect as subjects viewed the three flows. Across all 24 subjects, it took an average of 2:05 to feel comfortable with the first flow, 1:42 for the second, and 1:19 for the third. We found that in one-wall situations, stereopsis had the effect of flattening the learning curve; subjects with stereo took less time viewing the first and second flows than those without it, but by the third view, average times were very close. See Table 2.

Our higher field-of-regard trials, however, showed marked improvement over their low FOR counterparts. Subjects were at least 30 seconds faster at viewing each flow and 20 seconds faster at answering the questions for the non-stereo trials. They were marginally faster at two of the three flows in the stereo environment when given a high FOR.

Interestingly, high FOR with stereopsis turned off yielded faster average times than high FOR with stereopsis turned on. This discovery caused us to examine other aspects of user performance a little closer; this will be discussed in the following section.

	Flow A	Flow B	Flow C	Rankings
Low Immersion	2:51	2:44	1:33	2:10
Stereo Only	1:58	1:43	1:38	2:18
FOR Only	1:33	1:04	0:59	1:52
Full Immersion	2:00	1:18	1:08	2:23

Table 1: Average Times by Trial Type

5.1.2 Correctness

After the flows were shown to the subject, they were asked to rank the flows by some standard aerodynamic measures: divergence, velocity, turbulence, and separation. Flows A and C were fairly close in shape, while flow B was much different. Flows A and B were fairly close in speed while flow C was much different. A ranking could be wrong by only switching two neighboring values, or all three values could be misplaced. For this reason, we felt it was not sufficient to mark an answer simply as right or wrong. Subjects would instead get three points for a fully correct answer, two points for switching the closer two values that were next to each other, one point for switching the two more different values that were next to each other and no points for switching the end values or any other combination. A plot of the results is shown below in Figure 2, with the unweighted number of correct answers as a reference. The weighted values are normalized with respect to the number correct so that they can be viewed on the same scale.

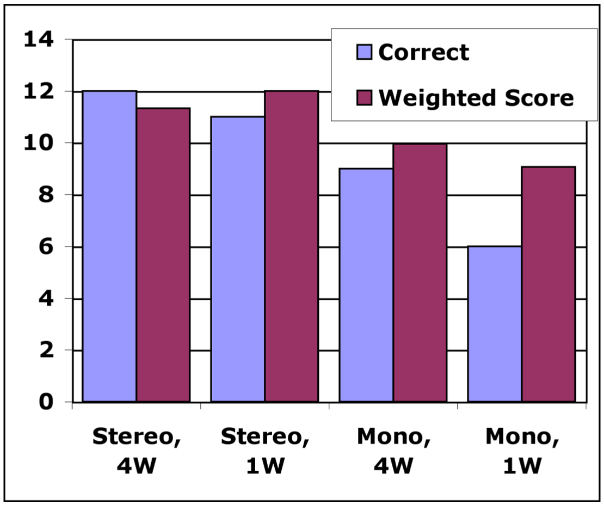

Figure 2: Weighted and non-weighted scores in the objective survey for the four tested conditions

In terms of correct answers, the case with minimal immersion got only half as many correct answers, with six, as the maximum immersion case, with twelve. The stereo, one walled case got eleven, and the mono four walled case got nine. This supports the claim that immersion helps to visualize and understand the data and suggests that stereo may be more important in this case than field of regard. When the scores were weighted the overall difference between cases fell some. The minimum case was raised to nine, where the maximum score was kept at twelve. Now, however, the one walled stereo case slightly outperformed the maximum immersion case.

The weighted results show more accurately if a subject understood most of the flow, but had a small error somewhere. These results tend to show that stereo plays the predominant role in correct understanding of the 3D data presented to a user.

5.1.3 Subjective Results

Subjects were given a subjective questionnaire upon completion of the trial. All users felt that the VE was useful and liked being able to view the flow from the inside. Several users gave us good feedback about changes we should make for future implementations of the VE.

Many people mentioned that a larger field of regard, in the form of more walls for the CAVE, would be useful. Those who had only one wall wanted all four, and those who had four walls wanted a 360°, rear-walled CAVE. An HMD may also help to mitigate this concern in the future.

Some subjects who had the lower immersion states complained of difficulty navigating. This was particularly true for the low field of view case. This was expected since the users who had a small field of regard would not have had as much area to move through. Another factor which could mitigate these concerns is a different navigation model; users had some trouble adapting to the flying metaphor and would have instead preferred an exocentric viewpoint in which they could rotate the flow instead of themselves.

One subject suggested using reference dimensions such as tick marks or rulers. We believe that while this could help some users get spatially oriented, it may cause others to experience cybersickness (see Discussion section below). Additionally, since our flow visualization did not have a real scale between the size of the particles and the size of the streamlines, it would be difficult to choose units for such a reference.

Finally, several users mentioned that they would prefer to see some abstract information about the flows displayed textually. We believe this is because users are accustomed to paper, 2D flow visualizations where most of the information comes, by necessity, from text descriptions. It should be easy enough, however, to add optional labels for the particles with information like velocity, position, charge, and temperature. Users would then be able to choose between the symbolic or the visual representations of these variables.

5.2 Discussion

- Why does stereo affect the learning curve?

  Stereopsis helps the users acclimate to the open 3D space faster by giving them more depth cues and thus enabling them to spatially relate the different streamlines in the flows. By the time users have viewed all three flows, however, even the non-stereo viewers have adapted to the CAVE and are able to relate the streamlines to each other and the sphere.

- Why does FOR make times faster?

  From our observations, users with the larger field of regard actually used the

Source	DF	SS	MS	F	P
Immersion Type	3	0.02467	0.00822	1.35	0.266
Flow	2	0.01304	0.00652	1.07	0.349
Interaction	6	0.00617	0.00103	0.17	0.9842
Error	60	0.36455	0.00608		
Total	71	0.40843			

Table 2: ANOVA Table for Level of Imersion and Flow Viewing Time

extra space, often zooming in closer (thus filling up more of the visual display space) than users with a smaller field of regard. They also tended to walk around in the CAVE more. More views of the flow seem to lead to greater understanding of the flow.

- Why is high FOR plus stereo slower than high FOR without stereo?

  We found that users were slower with stereo than without in the higher field of regard trials. We believe that the combination of stereo, high field of regard, and the rapidly flying streamlines leads to a 'wow' factor wherein users want to experiment with the capabilities of the CAVE. Mono vision does not have this appeal since the particles do not rush by the user's head in space. This may be only a partial explanation, and further research would be necessary to understand the exact causes.

- Why did we see so little cybersickness?

  None of our users mentioned feeling cybersickness at all. We believe that we experienced no cases of cybersickness because our immersive environment had few, sparse objects in it, so users did not experience the levels of cue conflict that they would have in a more populated environment. Additionally, while the particles moved, the environment as a whole remained fixed unless the user moved their position. Our information was rather abstract (despite being spatially related in the visualization, our ions were thousands of times bigger than real ions) compared to running through a maze or flying across an outdoor scene, so users' brains probably did not try to process the visual information into something 'real', but rather were able to comprehend it in a more symbolic or theoretical way.

6 Future Work

In future studies we would like to respond to some of the users subjective comments about the visualization. A six walled CAVE would make for an interesting experiment since many users commented on having a rear wall. We will also like to try to show more information to the user at one time. The color of the particles can be shifted to be proportional to the potential of the local grid space, and the size can be shifted to show local number density of particles. These were not used in this experiment because these properties would require more domain knowledge than most of our subjects would have had. A more exhaustive subject search would have to be done in this case.

While we believe that the charged particle flow is a good example of 3D data visualization, we would like to compare these results to other, different types of scientific data to confirm that our results apply to general viewing of large amounts of complex data. Specifically, we want to look at data sets that cover a much larger physical volume forcing the user to move throughout the environment to view all available data.

7 Conclusion

We designed a program to display complex 3D plasma flows. This was designed as a testbed to test immersive effects on complicated three dimensional data. Users were shown three flows and asked to rank them in various aerodynamic quantities. Field of regard and stereopsis were varied between subjects.

We found that having the full field of regard allowed by the CAVE decreased the time it took our subjects to get an understanding of the situation presented to them. Stereo had a very different effect however; while it did not speed up the time it took users to understand the flows, it helped to lower the learning curve in understanding them. Both stereo and a high field of regard had a positive effect on the subjects' ability to understand the particle flows. Combining stereo and a high field of regard, however, caused the subjects to take more time studying the flows, but their answers were more correct than with just a high field of regard. Users liked the VE for visualizing the data. Subjects with lower immersion generally had a harder time navigating around the environment than the users with higher immersion. Overall, it can be said that immersive environments are beneficial to the visualization of three dimensional scientific data.

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