# Visual Encodings for Immersive Visualization of Turbulent Combustion Data

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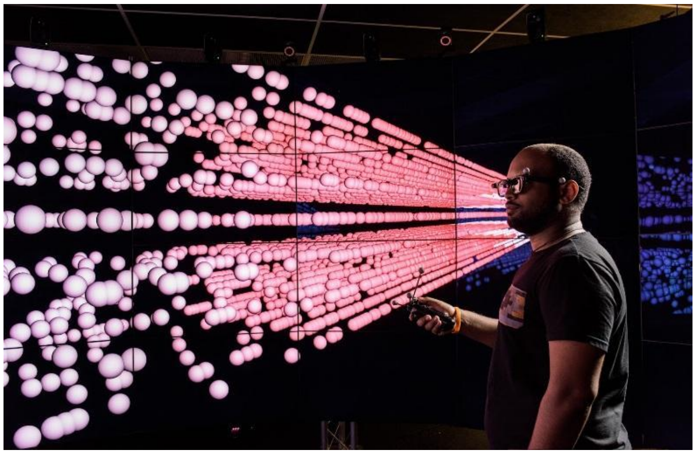

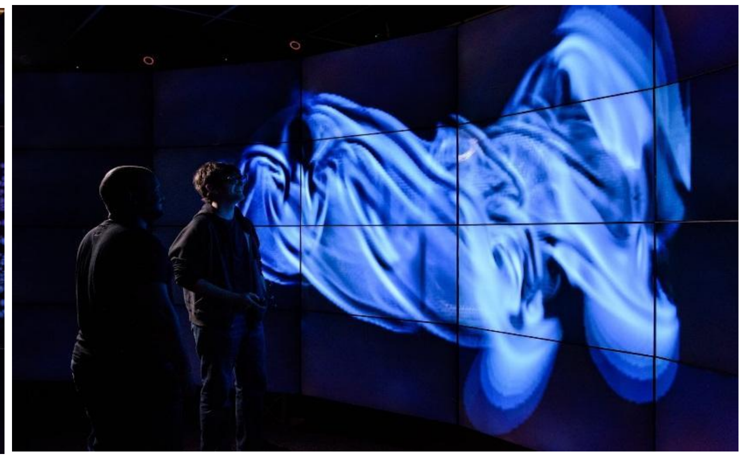

Figure 1 (left) shows point cloud rendering of the combustion dataset in CAVE2. Figure 2 (right) shows a volume rendering of a layer that is created when two fluids mix together in CAVE2.

## 1 INTRODUCTION

Computational simulation of turbulent flows can lead to more efficient designs of both power plants and jet engines. However, these simulations result in large scale, 3-dimensional, dense datasets which are difficult to explore numerically. These datasets may also contain errors, which can be due to configuration or parameter mistakes, or to incorrect approximations in the process of numerical modeling. Immersive visualization of these datasets can help debug the simulation process.

The goal of this NSF-REU and CRA-REU sponsored project is to effectively visualize high-density combustion data in a 3-dimensional immersive environment. While 3D visualizations of combustion data have been created in the past [4,5] , they are not immersive. To allow easier exploration of dense combustion data in a collaborative setting, we adapt two visual encodings, point clouds and volume rendering, to a virtual reality environment. We use GPU-acceleration to improve interaction rates. We apply these techniques to two combustion datasets. We evaluate the results together with a team of combustion specialists, and show how these encodings can provide insight into the structure of the flow.

## 2 METHODS

The two datasets used for this visualization come from the Computational Multiphase Transport Lab at the University of Illinois at Chicago [1], respectively from the Givi lab at the University of Pittsburgh. The first dataset is a computational simulation of the combustion performed within a scramjet engine. The data consists of 68,600 data points, each point corresponding to a fluid particle. The elements included in these data points include the X, Y, and Z coordinates in space, along with elements such as velocity, temperature, pressure, etc. This data is in a VTK format. The second dataset is a mixing layer simulation of 7M points, with the same structure as the first dataset.

We visualize the data within a virtual reality environment known as CAVE2 [2]. The CAVE2 is a circular wall of 72 monitors that creates a near 360 degree encapsulation of the users. The CAVE2 allows the use of motion tracking to explore and manipulate data shown within the environment. CAVE2 further provides 3D support to fully immerse the user in the data or environment.

After parsing the data and converting the files to a binary format, we visually encoded each particle as a 3-dimensional sphere using the OmegaLib library [3]. OmegaLib is a C++/Python graphics library which provides support for creating data visualizations and virtual reality environments within the CAVE2. The result of this encoding was a point cloud. We then color mapped the spheres according to the properties of the particles. For each element, we used a different value: red as temperature, blue as velocity, etc. Then, for these values, the less saturated the color was, the higher the value. Conversely, the more saturated a color was, the lower the value.

Each time step is encoded as a different point cloud model, and the user can scroll through these time steps to see the course of the combustion over time. We use GPU-acceleration to improve interaction rates. We have further visually encoded the data through a volume rendering technique, using OmegaLib's volume rendering module and a set of custom vertex and fragment shaders we have created.

## 3 RESULTS AND CONCLUSION

Figure 1 shows a point cloud rendering of the first dataset. This encoding has been quite successful in providing spatial information to the domain experts, who found a potential error in their own computational methods after viewing the visualization: the domain experts noticed multiple dropped particles (missing particles, at the bottom of the pictures) which resulted in gaps in the resulting simulation flow. This indicates a problem with the numerical simulation of the combustion flow. The experts had not noticed these problems earlier because their desktop visualizations projected the particles in 2 dimensions, which in turn masks the gaps.

Figure 2 shows shows a volume rendering of the second dataset. The experts easily noted the intricate layer that is created when two fluids mix together.

In conclusion, we have created a point cloud visualization that accurately displays combustion data in a 3D environment, while putting finishing touches on another method that allows for a visualization that reflects closely the combustion context. Our solution gives the user to ability to explore this space in a collaborative setting.

## ACKNOWLEDGMENTS

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