

# Integration of Augmented Reality with Computational Fluid Dynamics for Power Plant Training

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**Abstract**— *This research describes the motivations and technical approach for combining Augmented Reality with Computational Fluid Dynamics to develop materials for training on a large boiler of a coal-fired power plant. A number of different software were used for this approach including Gambit and Fluent for numerical simulation, 3dsMax for 3D modeling and visualization, and D'fusion for Augmented Reality. The result leverages the benefits of existing simulation methods and emerging interactive technologies to allow presenters to show characteristics of any numerical simulation in a vivid and convenient way.*

*The technical description of the simulation and visualization contains a series of complex steps and components, including the integration of the data, the construction of the geometry, and the analysis of the properties of flow within the boiler. The methods used to present this data with augmented reality can be expanded to many different areas.*

**Keywords:** Augmented Reality, Training, Power Plant, Boiler, CFD, Visualization

## 1 Introduction

Trainees at a coal-fired power station typically receive comprehensive training in boiler operation procedures through traditional two-dimensional (2D), non-scaled representations of components in a classroom environment. It is difficult to fully understand the complex workings of boiler operation in such environments. In general, there is a known issue in transferring learned concepts from a classroom setting to practical application in real world settings [1,2]. Improvements for the boiler training are being sought the development of computer simulations and different forms of interaction to enhance instruction. Initial efforts have already been made at Purdue University Calumet's Center for Innovation through Visualization and Simulation to combine computational fluid dynamics (CFD) and immersive 3D Visualization to enhance understanding of complex industrial processes [3]. These have been applied to develop a virtual boiler unit using Virtual Reality (VR) and CFD so that a 3D model could be used in the training process. However, the developed virtual package still has some limitations due to the necessity of specialized 3D

display. This can limit the accessibility for trainees to gain the full benefits of the VR model.

With the purpose of optimizing and maximizing the advantages of CFD and 3D visualization, a further effort is underway to develop methods to use standard equipment such as laptops and mobile devices to extend the training capabilities of the virtual boiler outside of a dedicated VR environment. The goals of this research are:

- To create a turbulent reacting CFD model for a specific boiler at a coal-fired power plant.
- To integrate CFD flow data and VR visualization models to provide a 3D representation of the boiler unit.
- To construct an AR environment to display and interact with simulation data combined with live elements.
- To provide a more efficient training media and software for the boiler operation crew.

Augmented Reality (AR) is being utilized to provide easy access to all the details of a virtual model in a 3D environment. This will provide a unique and intuitive method for trainees to interact with boiler components as well as simulated combustion and flow data. Initial efforts are utilizing printed 2D schematics of the boiler and components as the physical interface upon which 3D representations of the boiler and related data are displayed. Work is underway to integrate this method of interaction with 3D printed models of the boiler and components to increase the intuitive nature of the method even further. Trainees will then be provided with a variety of physical objects with which to explore the various operating conditions of the boiler.

## 2 Background

There are a number of technologies available to provide users with an interactive and immersive experience. While this study focuses on augmented reality, it is important to understand the relationship of augmented reality to related technologies such as virtual reality, augmented virtuality, and mobile devices. Through understanding the differences between these technologies, it becomes easier to utilize the

strengths of each for specific purposes, thus increasing the benefit to the users. Milgram proposed a Mixed Reality Continuum (figure 1) which categorizes technologies on a scale ranging from a completely real environment through a completely virtual environment [4]. It is important to note that in virtual reality, the user is immersed in computer generated imagery and is cut off from the real world. While this is beneficial in many circumstances, it also creates some issues such as potential disconnects between the virtual objects and their real world counterparts.

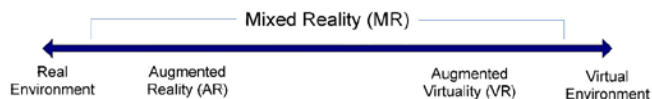


Figure 1. Milgram's Mixed Reality Continuum.

With AR, a user is able to maintain a connection with real world, while still enjoying the benefits of 3D models and useful information from the virtual world. AR is type of technology that combines 3D virtual objects with real world imagery in real time [5]. A typical implementation of AR uses a camera connected to a computer to recognize patterns from the real world and then display useful information on top of the live video display. With the advances in mobile technology in recent years, Mobile AR applications are surfacing for phones and tablets to provide augmented interfaces for maps, social networking, gaming, and educational training [6-9]. One study of particular note explored the usage of augmented reality for maintenance within a power plant. This effort focused on developing a prototype system to assist with actual maintenance operations by displaying relevant text and schematic information on-site [10]. While this wasn't specifically an educational application, it provided useful insights into the implementation of a mobile augmented reality system within the power plant environment.

This paper focuses on more detailed operations and the phenomena occurring within the power plant boiler and turbine. The combination of augmented reality for educational training is explored by combining the technology with computer simulated combustion and fluid flows and Photorealistic representations of the boiler at a coal-fired power plant.

### 3 Methodology

#### 3.1 Simulation

Gambit® is used to preprocess the model. The geometry obtained from Gambit® will be imported into Fluent® for the fluid computation [11,12]. In order to get correct results in Fluent®, inlets, outlets and other conditions must be set up appropriately while building the geometry of the boiler.

The simulation was divided into two activities:

**Build the geometry:** The model of the boiler was built based on the data provided by CIVS. Each cyclone has four inlets, three of them are for air input, and the other is for coal. Figure

1a shows a 2D cross-section of the boiler model in ANSYS, while figure 1b shows post-processed results within Paraview.

The Geometry obtained from Gambit® was meshed and imported into Fluent® to simulate the all characteristics inside the boiler, such as temperature distribution, velocity temperature and tracks of discrete particles. Since further calculation and analysis would be based on the meshed geometry, the meshed graph needs to be as accurate as possible.

The graphic of the component will be calculated for the detailed flow characteristics and detailed reaction. In this case, the velocity and flow turbulence characteristics are calculated.

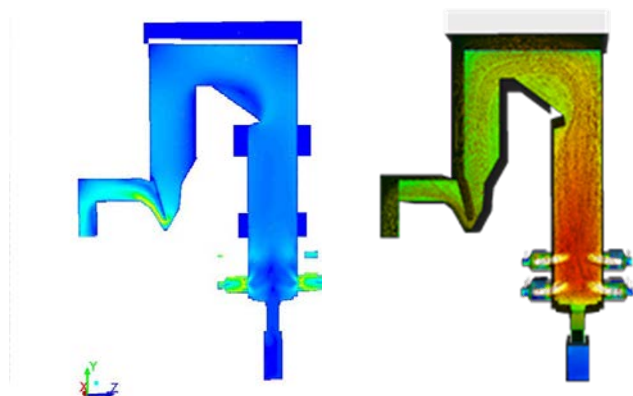


Figure 2. A 2D cross-section of the boiler CFD results in ANSYS (left), and 3D results visualized in Paraview (right).

Procedures included the following steps:

1. Read the data: First, the data of the meshed geometry of the boiler should be loaded into Fluent®. This will ensure that the mesh is correct and is able to be processed
2. Check the dimensions: Before beginning calculations, checking needs to be done to make sure all the scale and dimensions are correct. In order to get the precise calculation, the dimensions in Fluent® should correspond to the geometry drawn in Gambit® before setting data [13].
3. Set data: In Fluent®, the properties and boundary conditions (including pressure, temperature, velocities of the inlets and the outlet) of the system should be set first to enable the model to flow.

The air inlets of the boiler should be a velocity-inlet, the coal inlet needs Discrete Particle Model (DPM in Fluent®) and the outlet should be set as a pressure-outlet. The material used in the calculation is air and coal.

4. Check data: After setting the data, all the data should be checked to ensure the correct characteristic of the flow.

Otherwise, the flow will not display the actual situation of the actions taken in the power plant, and the data may not be correct.

5. Calculate: In this case, the velocity of the flow is calculated. The number of iterations is 10,000 in order to get the converged results. Usually, if the continuity shown in the figure can be stable and be below  $1e-3$ , the results would be accurate enough
6. Display the calculation: The results show the detailed velocity changes inside the boiler.

### 3.2 Visualization

The simulation results were brought into Paraview for post-processing and to generate 3D models representing certain aspects of the data such as temperature and velocity using vectors, streamlines, and color gradients to represent varying data values [14].

The resulting models were exported from Paraview and brought into 3dsMax to integrate with additional models for trainees to better understand simulation results in the context of the real boiler in the field [15]. 3D models of the surrounding structure and equipment was created and registered with the boiler simulation results based on drawings and specification provided by the power plant. Additional elements such as animated processes and flame particle effects were also included to increase the realism of the model.

In addition to the facility model and processes, aerial imagery of the real facility was imported and registered to align with the structures. This provided additional elements of realism for the trainees to relate the simulation results to the real environment.

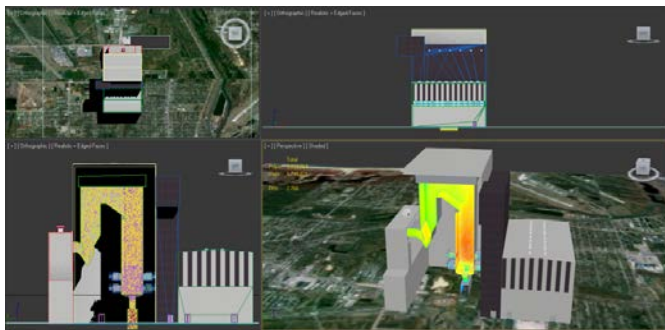


Figure 3. 3D CFD results from Paraview are combined with a photorealistic model of the surrounding structure in 3dsMax.

Once simulation and photorealistic models were combined, the models were exported and used as input for AR software. Several AR software were evaluated for this research. The high-level AR tool D'fusion® was selected for its flexibility and ease of development.

By using D'fusion®, a real-time AR environment can be set up and rendered [16]. The tracking system needs a tracker such as a paper with special marks, a camera to capture the tracker's information and source code files that tell the system to build certain models based on the tracker's location [17].

First, a meshed model of the virtual scene is imported into D'fusion. Then several camera drivers and tracking code will be linked into the system. Finally, after multiple tests, the software is able to display the operation and the case on the screen

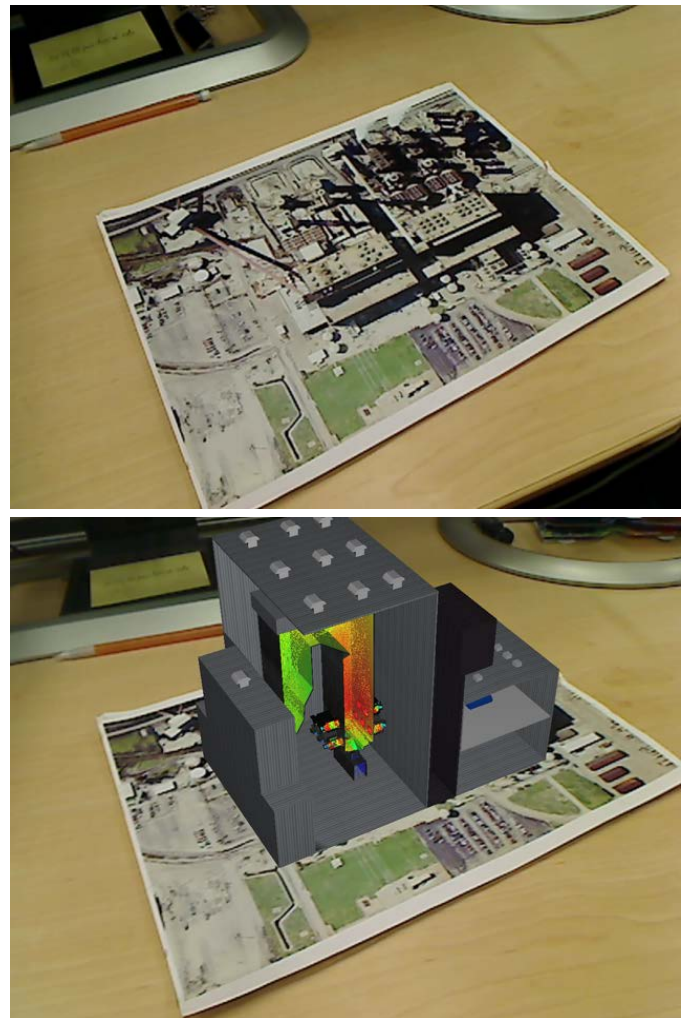


Figure 4. Aerial photograph of the power plant serves as the target image for the AR software (Top). The Boiler CFD results and surrounding structure are registered and displayed over top of the image (Bottom).

## 4 Results

The CFD simulation method, 3DS Max modeling, and D'fusion toolkit themselves have been used for many years. But this project is the first time to make it an integrated system



for engineering projects. The transition between software is the main problem. Because of the rapid development of techniques, file formats are different for 3D model. Thus, details are being lost during converting files such as textures and the directions of some patterning. New algorithm is highly expected in order to uniform the format.

Another problem to be optimized is the function of the outcome system. By using packaged software to develop the AR environment has its limitation. Further powerful function like regional / full view switch of a model or all dimensional tracking was not achieved.

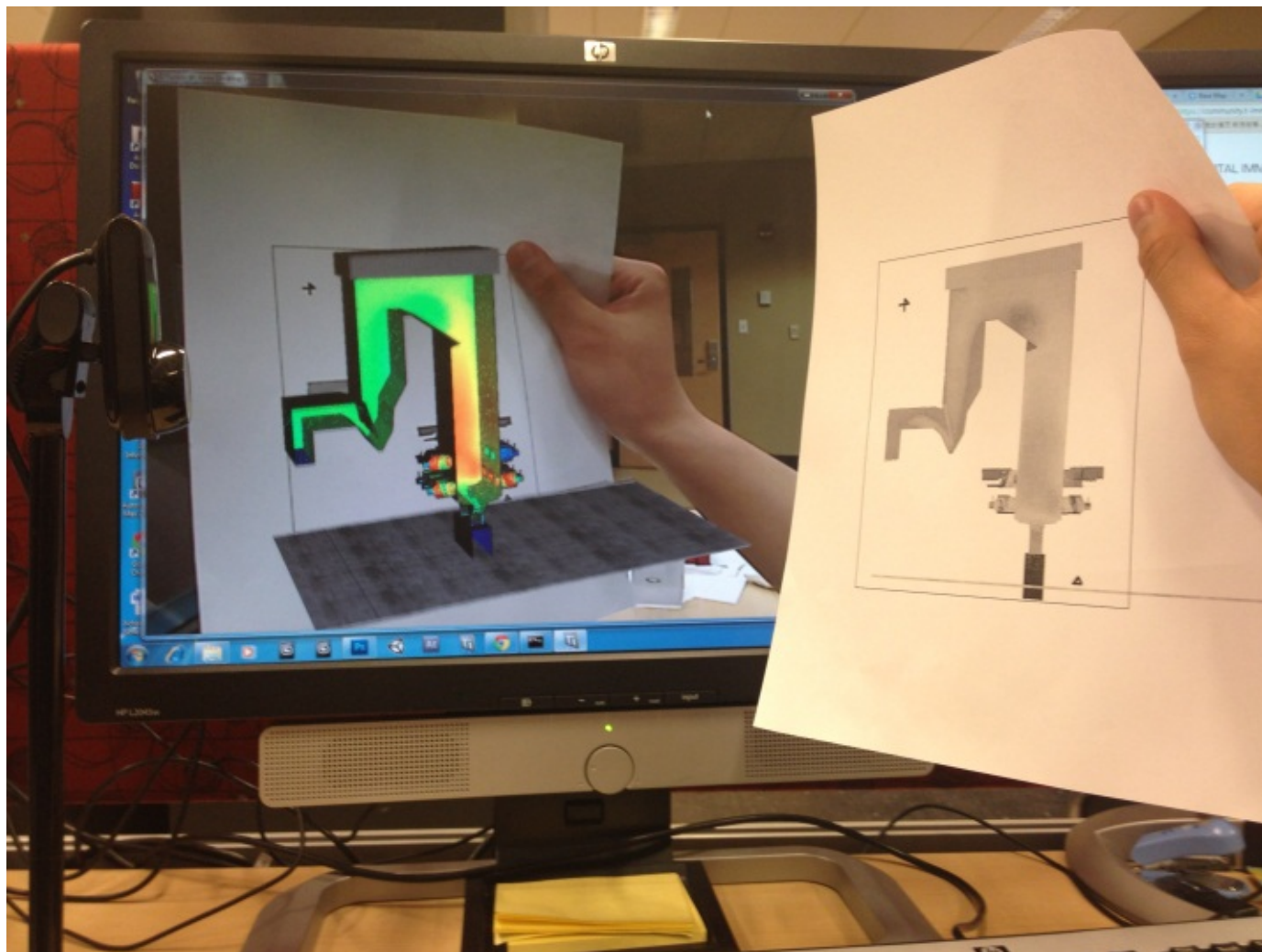


Figure 5. Schematic drawings are used as target images and registered to align simulation results with relevant drawing details.

## 5 Conclusions

This research has developed a method of integrating CFD simulation results with photorealistic 3D models for the purpose of power plant training using augmented reality. The method includes numeric simulation, post processing, modeling of associated 3D structures, and registration with relevant technical drawings.

Future work will build additional options to interface with CFD data through AR, explore additional methods to integrate AR into training and assess their effectiveness.

## 6 Acknowledgment

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