A Study on Visualization for EFD/CFD Integration

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ABSTRACT

Integration of EFD and CFD is important to supplement their respective drawbacks, and enhance efficiency and reliability of aerodynamic simulations. To achieve this, visualization is an important component to help users compare EFD/CFD data. This poster proposes a unified approach on visualization for EFD/CFD integration. Two major components of our system are difference visualization, and gradient edge detection. These components make users easier to understand difference between EFD/CFD data, and also displacements of specific characteristic points between each data.

KEYWORDS: Visualization, EFD/CFD Integration, EFD, CFD.

1 INTRODUCTION

Fluid dynamics is an important academic field, applied to various study of natural phenomena, and developments of engineering products. In the field of aerospace, EFD (Experimental Fluid Dynamics) has been applied for almost a hundred years, and recently CFD (Computational Fluid Dynamics) has been very important as well, thanks to drastic evolution of computational performance.

However, EFD and CFD have respective drawbacks. Although EFD has higher reliability than CFD, it has several limitations including costs and measurement methods. On the other hand, CFD enables fast and cost effective simulation. However, the results of CFD are not reliable enough to be applied independently, and therefore validations by EFD are often needed.

Considering such drawbacks of each technique, it is reasonable to think that integration of EFD/CFD is important to supplement them and fulfil more efficient and accurate simulation through their mutual support.

There are few well-known systems on the integration of EFD/CFD in the field of aerospace. ViDI (Virtual Diagnostics Interface System)[1] by NASA Langley laboratory is a typical EFD/CFD integrated system, which compares real-time EFD results and pre-computed CFD results and quickly visualizes their difference. Also, JAXA (Japan Aerospace Exploration Agency) is developing a concurrent EFD/CFD integration system so called Digital/Analog hybrid wind-tunnel[2]. In such systems, visualization is a very important technical component to help users compare and analyze the results of EFD/CFD.

This poster presents our study on visualization for EFD/CFD integration. Our system first unifies grid structures of EFD/CFD data, and then visualizes the difference between the results. This poster also discusses future plans of our study.

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2 AIR PRESSURE DATA

2.1 EFD Data

As input data, we apply air pressure values on the surface of an aeroplane. EFD data of air pressure values is observed in a wind tunnel experiment by adopting PSP (Pressure-Sensitive Paint)[3], which is a molecular sensor paint that becomes luminescent when air pressure is low. Air pressure data is often used for validations of EFD/CFD data, since PSP enables continuous and finely measurement.

We construct the EFD data as a triangular mesh, by connecting the measurement points of air pressures in the experiment.

2.2 CFD Data

In our study, CFD data of air pressure values is generated with an automated mesh generation and a fast solver. We formulated the fluid dynamics around a model of an aeroplane by finite volume method, and solved it by MUSCL (Monotone Upstream centered Scheme for Conservation Laws) method. The CFD data forms a mixture of triangular and quadrilateral elements, where air pressure values are assigned to every vertex of the elements.

3 VISUALIZATION OF EFD/CFD DATA

3.1 Data Unification

Our study first unifies the grid structure of the EFD/CFD data by mapping air pressure values of CFD data onto vertices of EFD data. Following is the procedure of the data unification:

1. Project all vertices of EFD/CFD data onto an adequate plane.
2. Find the coordinate *Ve'* on CFD data which corresponds to the vertex *Ve* on EFD data
3. Find rectangular cell *Cc* on CFD data, which encloses *Ve'*.
4. Calculate the air pressure value at *Ve'* on CFD data by interpolating the air pressure values of four vertices of *Cc*.
5. Repeat 2 and 3 for all vertices of the EFD data.

Figure 1 illustrates the above procedure.

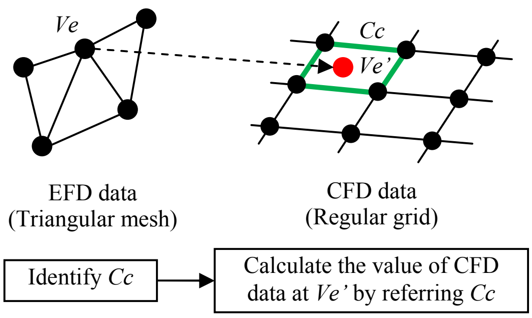

Figure 1. Data unification

3.2 Distribution Visualization

In our implementation, we simply transfer air pressure values of every vertex into colors. Currently we apply a simple transfer function: $H = (P - P_{min}) / (P_{max} - P_{min})$. Here, P denotes an air pressure value, P_{min} and P_{max} are minimum and maximum values of the air pressure, and H is the hue of the corresponding color. H=0 corresponds to blue, H=1/3 corresponds to green, H=2/3 corresponds to yellow, and H=1 corresponds to red.

After calculating colors of every vertex, our implementation renders the polygons, by simply interpolating the colors inside the polygons from the colors of their vertices. Figure 2 and 3 show results of the EFD and CFD data respectively. Most importantly, our system also visualizes the difference between the EFD/CFD data. This distribution visualization plays significant role to help users understand how the difference of EFD/CFD results distributes.

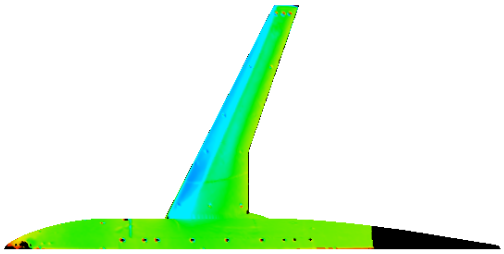

Figure 2. Result of the EFD data

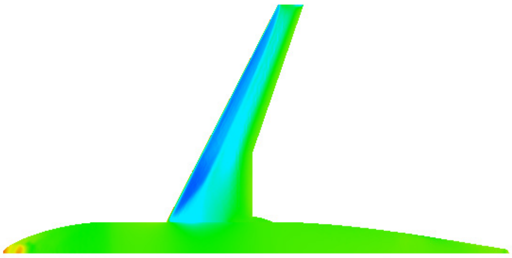

Figure 3. Result of the CFD data

3.3 Gradient Edge Detection

We have also implemented a component to detect gradient edges, where air pressure values sharply vary. Visualizing gradient edges of air pressures is important for fluid dynamics analysis, because singularities such as shockwaves and vortices can be discovered around gradient edges. Our implementation also displays a set of two gradient edges detected from EFD/CFD results simultaneously, so users can easily understand displacements of specific singularities between the two data. Following is the processing flow of visualizing gradient edges:

1. Render the surface, and preserve the pixel values into a framebuffer.
2. Read the pixel values from the framebuffer, and apply the Laplacian filtering to the pixel values to detect edges.
3. Acquire positions of vertices on the window space, and associate pixel values of the result of Laplacian filtering to the vertices. Our implementation calls gluProject function to acquire the positions.
4. Highlight vertices with pixel values larger than a user-defined threshold value.

Figure 4 shows an example of visualization result representing gradient edges of air pressure values. The edges are detected from each of EFD/CFD data, and displayed one on the top of the other. Pink and black points highlight vertices detected from the EFD/CFD data respectively. This result shows that edges are detected at different positions comparing both data. Since it may denote significant errors of EFD or CFD data, we need to carefully observe and discuss the visualization results.

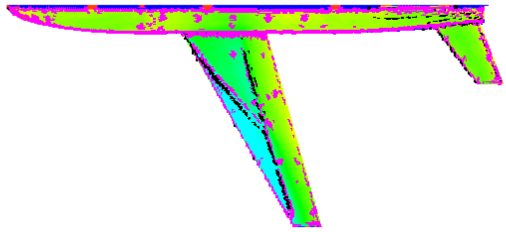

Figure 4. Gradient edges of air pressure values.

4 Conclusion and Future Work

We have presented an approach on visualization for EFD/CFD integration. Our work has focused on visualizing air pressure values of EFD/CFD data and their difference. Since our EFD/CFD data form different structures of grids, we unified the data by mapping the CFD data onto the EFD data. Then, we developed a component to visualize the air pressure values of the EFD/CFD data and difference between them. We also implemented a component to visualize gradient edges of air pressure values detected from the EFD/CFD data.

Our study is in early stage of applying another input data of air flow velocity behind an aeroplane. Our implementation currently visualizes the vectors with colors, which denote the velocity distribution of the vectors, as shown in Figure 5. In the future, we will develop a component to visualize difference of the air flow vectors of EFD/CFD data, and also their gradient edges.

Another issue is improvement of edge detection of air pressure values. Our implementation currently detects the gradient edges by adopting visual edge detection such as Laplacian filtering. However, this component is vulnerable to visual effect such as light changes, thus we are currently working on adopting edge detection on 3D spaces.

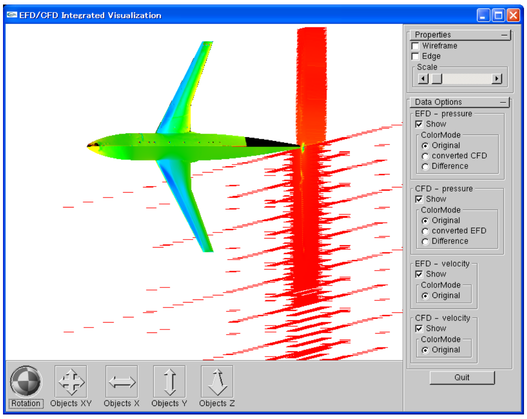

Figure 5. Unified air flow and pressure visualization.

References

[1] R. J. Schwarts, G. A. Fleming, "Virtual Diagnostics Interface: Real Time Comparison of Experimental Data and CFD Predictions for a NASA Ares I-Like Vehicle", ICIASF 2007, pp. 1-12, June 2007.

[2] S. Watanabe, S. Kuchi-ishi, T. Aoyama, "A Prototype System Towards EFD/CFD Integration: Digital/Analog-Hybrid Wind Tunnel", Proceedings of 27th Congress of the International Council of the Aeronautical Sciences, 2010.

[3] K. Nakakita, K. Mitsuo, M. Kurita, S. Watanabe, K. Yamamoto, J. Mukai, "CFD Code validation Using Pressure-Sensitive Paint Measurement", JAXA-SP-04-012, 2004.