Visualizing Turbulent Flow

Greg P. Johnson[1], Kelly Gaither[1], Victor Calo[2]

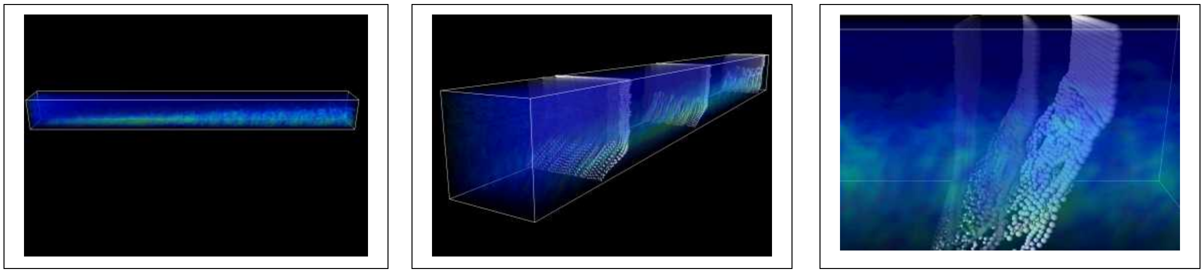


Figure 1: Three views of fluid flow over a flat plate showing the transition from laminar to turbulent.

Introduction

The images shown in Figure 1 display a single time step of a turbulent flow simulation computed by Dr. Thomas J. R. Hughes, Professor of Aerospace Engineering, and Victor Calo at The University of Texas at Austin. This research examines how a fluid running over a flat plate suddenly becomes turbulent. The smooth flow seen at the left-hand side of the volume has low-amplitude fluctuations that interact with the smooth, laminar boundary layer of the fluid. As the energy of the fluctuations is convected downward into the boundary layer, there is a sudden explosion of the entire flow into turbulence. The left-most image of Figure 1 displays the left to right nature of the fluid as it passes over the flat plate, showing the turbulent boundary layer. The middle image shows the volumetric flow with sheet of particles inserted at designated locations to show increasing turbulent behavior. The right-most image in Figure 1 is a close up of particle sheets showing local velocity fluctuations inside the turbulent boundary layer.

Turbulent flow has been under study by many groups for some time, and has applications in turbomachinery design, aerodynamics, and electronic cooling devices. The goal of the simulations and the corresponding visualizations is to be able to determine which conditions in the flow cause turbulent behavior. More precisely, the goal is to find turbulent spots in the flow. These spots have a well defined and characteristic form and grow and drift downstream to coalesce and produce the final turbulent boundary layer. Conditions causing turbulent spots, however, are not well defined and are the subject of study in this work. Knowing the cause of turbulence would allow computational fluid dynamicists to design and build vehicles that avoid these conditions. Current methods for visualizing turbulent fluid flow, however, do not allow the researcher the ability to interactively navigate through large-scale volumetric data, and preclude the user from utilizing the visualization as an investigative tool for knowledge discovery. The turbulent flow visualizer presented here was specifically designed to interactively investigate theoretical conditions under which turbulent flow occurs.

Interactive Visualization of Turbulent Spots

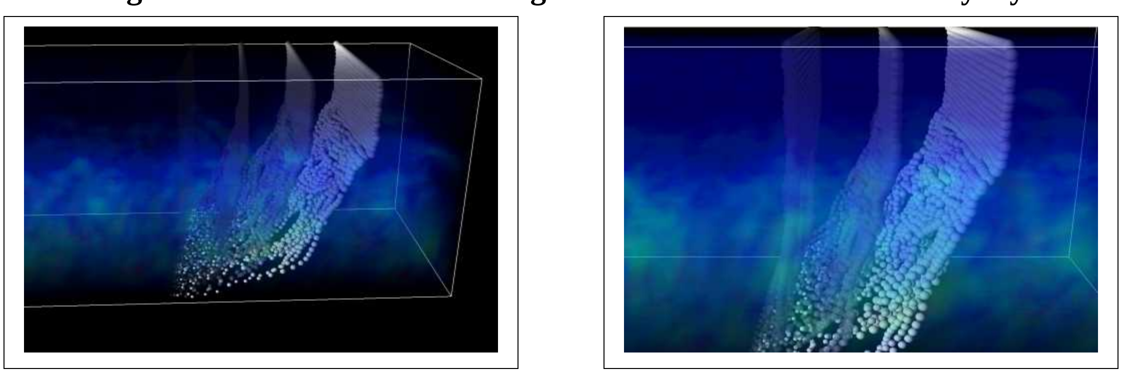
[1] Texas Advanced Computing Center, The University of Texas at Austin
[2] Institute for Computational and Engineering Sciences, The University of Texas at Austin

One theory being investigated is that turbulent spots occur where boundary layer particles "rotate"--particles low in the boundary layer move to higher positions and particles high in the boundary layer move to lower positions. In this system, interactive visualization techniques are being used to examine those locations in the boundary layer where this occurs. By interactively examining the magnitude of the velocity fluctuations, likely candidates for this behavior can be found. When the velocity fluctuation at a point gets very high, this particle rotation may occur. Interactive three-dimensional visualization techniques are necessary to visually prove this hypothesis, but current systems preclude interactive performance because of the massive size of the simulation data (150 time steps, each time step ~2GB, total size 300 GB).

To facilitate 3D interactive viewing, data is streamed into the turbulent flow visualizer using streamer threads. This is fast and eliminates the need for massive amounts of memory. Because a low cost (both time and memory) global view of the flow is needed to determine general turbulent behavior, two-dimensional texture mapping is used to render the volume. The volume is shaded with color mapped values of the magnitude of the velocity fluctuation from the average velocity to give the overall impression of flow in the boundary layer. At the top of the flow (the free stream) the velocity fluctuation is very low. At the bottom (the boundary layer) the velocity fluctuation is very high.

Particle sheets are seeded at positions where it appears the velocity fluctuation is growing rapidly. The visualizations are then examined to determine whether particles in the boundary layer move upwards and downwards, verifying the hypothesis that turbulent spots occur where boundary layer particles “rotate”. To allow interactive performance on multivariate visualization primitives, the particles are visualized as texture mapped quads that are made to look like spheres. The texture maps contain a faux specular highlight, and the quads are positioned to be orthogonal to the view position, thus giving the appearance of a sphere. The size and color of the spheres can be manipulated to reflect properties such as magnitude and life span. Particle sheets are shown in Figure 2.

Figure 2: Particle sheets showing flow in the turbulent boundary layer.



The turbulent flow visualizer was developed to provide interactive tools to locate turbulent spots and investigate flow conditions under which they occur. Preliminary results suggest that the initial hypothesis -- turbulent flow occurs where boundary layer particles rotate -- is true. In the future, the turbulent flow visualizer will be extended to automatically detect these regions of interest and track their behavior over time.