CAREER: The Role of Turbulence, Coherent Structures, and Intermittency for Controlling Transport in Multiphase Plumes in the Environment

DUNCAN B. BRYANT[1]
[1]*Texas A&M University, Zachry Department of Civil Engineering, College Station, TX 77843, USA. E-mail: duncanb@tamu.edu*

ABSTRACT: This paper details the research and experiences of three Texas A&M University students while studying abroad at the University of Karlsruhe in Karlsruhe, Germany. First, it addresses the research performed by one student in the laboratory's shallow water basin. This large basin, 12.5 meters by 5.5 meters, was used to study tidal vortices using surface particle image velocimetry. Tidal vortices can impact flushing of estuary systems leading to environmental problems. Using the velocity fields from the test, vortex identification could be performed. Secondly, this paper addresses the cultural experience of the students and details two important trips taken to learn more about the German government and the European Union system. Finally, this paper details recommendations for future programs.

INTRODUCTION

This International Research and Education in Engineering (IREE) project supplements Dr. S. A. Socolofsky's current National Science Foundation (NSF) project CTS-0348572, awarded to the Texas Engineering Experiment Station, College Station, TX, USA. The award applies advanced laboratory experimental methods to understand turbulence and mixing properties in environmental fluid flows. The educational component of the award develops curriculum in environmental fluid mechanics.

During the summer of 2007, Texas A&M University's Zachry Department of Civil Engineering Coastal and Ocean Division sent three students to conduct research at the University of Karlsruhe in Karlsruhe, Germany using funds available from the National Science Foundation. The goal of this program was to give two undergraduates and one graduate student an opportunity to do research in a different country while allowing for international cooperation and cultural growth.

Karlsruhe is located in southwestern Germany next to the Rhine River, bordering the famous Black Forest and is only a 45 minute bike ride from France. Karlsruhe was founded as the wilderness retreat for Karl Wilhelm who built a palace there in 1715.

Karlsruhe is home to the Federal Constitution Court and Federal Court of Justice, which is the highest appeals court in Germany.

The group departed for Germany on May 17, 2007 and returned on August 17, 2007. Bryan Alldredge and Kate Hagan were the two undergraduates who participated and Duncan Bryant was the graduate student.

The University of Karlsruhe's Department of Civil Engineering has a state of the art laboratory for studying environmental fluid flows. It includes multiple flumes for open channel flow studies, a large shallow water basin, a complete automated pumping system, laser systems, and other velocity measurement tools. Most importantly, the lab had multiple systems to determine the water velocity in a flow using particle image velocimetry.

Particle image velocimetry (PIV) uses images taken of the particles in a fluid flow to determine the velocity field, which is simply the particle displacement divided by the time in between pictures (Raffel et al., 1998). This velocity field can be used to determine vorticity, turbulent properties, and to identify coherent structures.

The facilities at the University of Karlsruhe allowed for experiments to be conducted pertaining to the formation and life of tidal vortices**.** Wells et al. (2003) first described how these large two-dimensional vortices form as water flows through an inlet during the ebb tide. The fluid exiting the inlet has a much higher velocity than the surrounding ocean water. This results in a large velocity gradient which causes the fluid to curl and form a vortex. Thus, a vortex forms on each side of the inlet spinning in opposite directions. The vortices then propagate towards one another under the influence of the other's flow field. When the vortices are sufficiently close, they produce their own forward motion away from the inlet. However, if the flood tide is strong enough or if the time is short enough, the vortices may be drawn back into the inlet. The case of the vortex being drawn back into the inlet can reduce estuary flushing and minimize water quality.

However, Wells et al. (2003) only considered laminar flows and highly idealized inlets. The purpose of the research time in Germany was to study these flows under turbulent conditions and under different inlet configurations. Changing inlet configurations provides information on tidal vortex formations under conditions that better represent what is found in nature. In particular, tidal inlets that were not aligned and that had jetties were tested.

RESEARCH ACTIVITIES AND ACCOMPLISHMENTS OF THE INTERNATIONAL COOPERATION

Research performed at the University of Karlsruhe allowed for the use of a shallow water basin with reversable flow that allowed for tidal simulation. The basin size was 12.5 meters long by 5.5 meters wide. This basin was ideal to study the generation of large two-dimensional tidal vortices due to its large size, thus eliminating side wall effects and reversible flow ability. Previously, little experimental data existed on such a generation. Barriers were constructed inside the basin to create the inlet configuration. In total, 32

different experiments were conducted each providing 220 seconds of images over an area 3 meters long and 1 meter wide. The cameras were positioned to capture the tidal vortex from formation at the inlet to downstream propagation. The cameras positioned above the flow imaged the floating particles at 16Hz. The images of the floating particles allowed for particle image velocimetry of the surface flow. Several different senerios were tested at the laboratory in Karlsruhe.

Important parameters of these vortex formations include inlet width, tidal period, maximum inlet velocity, water depth, inlet alignment, jetty length and inlet length. Some of these parameters, such as inlet width, tidal period, and maximum inlet velocity had already been studied. The tidal period for the experiments was set at 40 seconds. The reason for the 220 second experiment length was to hopefully create a pseudo-steady state where the vortex generation by the fourth and fifth period is nearly identical. Experiments conducted in Germany were designed to evaluate the other parameters. Three experiments were conducted to evaluate the effect of water depth. Fifteen experiments examined the effects of inlet alignment while the remaining looked at the effects of changes in jetty or inlet length. After the experiments were conducted, PIV processing was performed and the vector maps could be used to better understand the turbulence, upwelling, size, and effects on mixing within these vortices.

The figure below is one vector map from the images taken. As we can see the vortex is very large, nearly as wide as the camera's field of view. Using this image, parameters such as vorticity could easily be calculated.

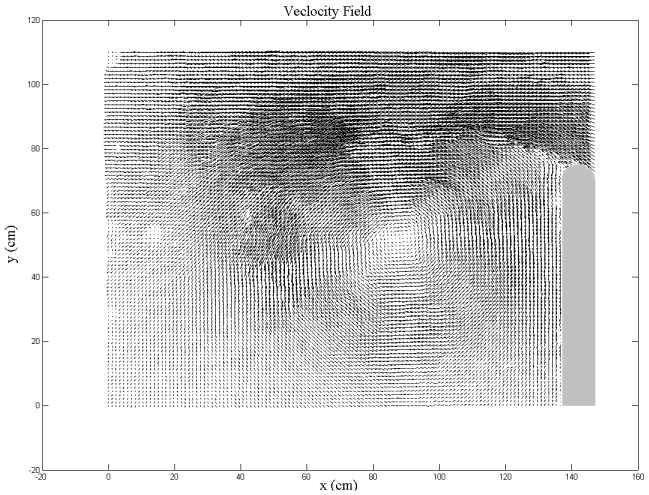

Figure 1.- Velocity Field of a Tidal Vortex

Another useful tool in studying these vortex flows is the swirl strength. The swirl strength was shown by Adrian et al. (2000) to accurately identify vortices. Though the large vortex is easy to see in the vector map, smaller vortices exist as they shed from the inlet. Figure 2 shows the swirl strength contour for the same vector map show in Figure 1.

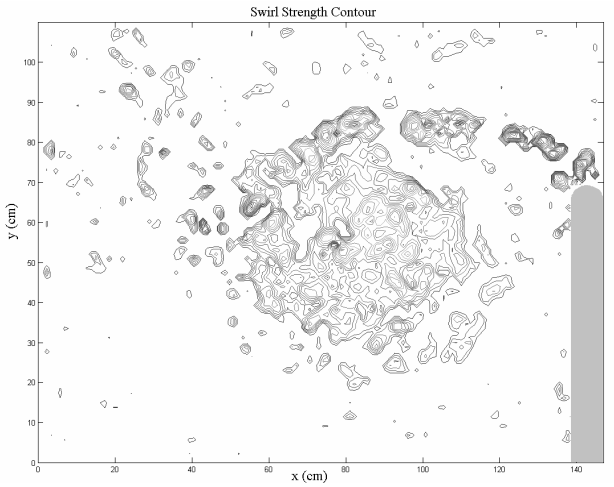

Figure 2.- Swirl Strength Contour of a Tidal Vortex

The smaller contour areas above the large vortex are an example of these smaller vortices. The interaction between these vortices of different scales is also important to turbulent parameters.

BROADER IMPACTS OF THE INTERNATIONAL TRAVEL

Many students from all over the world study at Texas A&M University. Though this allows for some insight into other cultures, it doesn't leave one with a clear picture like being immersed into another culture does. Studying abroad in Germany broadened my knowledge of another culture. While conducting research at the University of Karlsruhe, I had the opportunity to learn about both the German language and way of life. The students and the professors at the university were helpful in aiding me in adjusting to life in Germany and any language barriers I encountered. The chance to perform research in another country and learn about another culture was invaluable. At the University of Karlsruhe, students from Germany, Italy, France, Chile, India, Luxemburg, Spain, and the United States were all represented. This allowed for time to be spent learning about lots of different places and people.

Different trips were organized to enhance our overall knowledge of the German political system and the European Union. A trip to Berlin included a visit to the Reichstag Building, which is home to the German Parliament. The building housed the parliament from 1894 until 1933 when it was destroyed by fire. In 1990 the ceremonial reunification of Germany took place inside the Reichstag and after much debate it was decided to use the Reichstag as the home of the reunified parliament. After intensive restoration and the addition of a modern glass dome, the parliament began using the building again in 1999. The glass dome allows for a direct view into the parliament meetings below, giving the feeling of a transparent government. While in Germany, it was also important to learn about the European Union which governs trade and currency for 27 different European Countries.

Just across the border of Germany is Strasbourg, France, which is home to the European Union Parliament. Currently the European Union Parliament has two homes: Strasbourg, France and Brussels, Belgium. However, the Strasbourg home is considered to handle more critical issues. Overall, the European Union has unified currency across almost all of its members, increasing trade and allowing for easy travel.

DISCUSSION AND SUMMARY

The opportunity to perform research at the University of Karlsruhe provided significant data in understanding tidal vortex formation and greatly expanded our knowledge of the German culture. The 32 experiments performed in the shallow water basin will provide insight into the effects of inlet offset, water depth, and jetty length on vortex formation and how this influences estuary flushing. The data amounts to a total of 208,000 images.

The cultural experience was just as invaluable as the work performed. The ability to work with students of another country gave insight to social similarities and differences. It also showed the difference between education systems. This positive experience showed the need for international cooperation between institutes of higher learning.

Recommendations for future programs are to make it mandatory to visit sights of historical and political importance. Without our trips to visit the German and European Union Parliament, I would know very little about the government system in Germany or Europe. These are topics not common to an engineering curriculum. Also the ability to study the language before departing is critical. Finally, the program was very successful leading to an increase in research, cultural diversity, and international cooperation.

ACKNOWLEDGEMENTS

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BRIEF BIOGRAPHIES OF RESEARCHERS

Duncan B. Bryant received his B.S. in 2005 and M.S. in 2006 from Clemson University. He is currently a Ph.D. candidate at Texas A&M University studying coherent structures in environmental flows, with particular interest in multiphase plumes in the Zachry Department of Civil Engineering, Coastal and Ocean Division.