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

JOHN C. BANDAS[1]

[1]*Texas A&M University, Zachry Department of Civil Engineering, College Station, TX 77843, USA. E-mail: jcbandas@gmail.com*

ABSTRACT: John Bandas visited the Institute for Hydromechanics at the University of Karlsruhe, Germany, between May and August 2008 to conduct research through the International Research and Education in Engineering (IREE) program of the National Science Foundation (NSF). This research consisted of laboratory experiments in dense plumes in a crossflow and sloping bottom, which resulted in the identification of qualitative features and model data. Two undergraduate students and one graduate student visited the IfH to conduct experiments in environmental fluid mechanics. This trip is part of Dr. Scott Socolofsky's CAREER award, which is working to develop models for international student exchange opportunities for engineering students with limited foreign language skills. This program allows the undergraduate students to attend three-month internships, complete an undergraduate thesis at the host institution, and receive independent study credit at their home institution. This program also allows the graduate student to utilize the host institutions laboratories to work towards completing her Masters of Science thesis.

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 multiphase plumes.

Three students from Texas A&M University (John Bandas, Autumn Kidwell, and Kerri Whilden) conducted research at the Institute for Hydromechanics at the University of Karlsruhe from May 15 to August 15, 2008. The IfH has an environmental fluid mechanics group that performs state of the art research and is visited by students and scientists from all over the world interested in numerical and experimental analysis of environmental fluid mechanics. Students worked on current projects at the host institution and on projects that have further collaboration planned between IfH and A&M. The IfH provided fantastic hosting for scientific achievements and cultural experience.

In addition to assisting the other students, my research was the analysis of dense plumes in a cross flow with a sloping bottom. Around the world, particularly in the Gulf of Oman but not limited to locations such as Boston and Sydney, desalination plants are becoming an efficient and environmentally practical option for providing fresh water to civilization. The two environmental challenges for desalination plants are the control of the inlet current so that fish and sealife may escape, and the management of the super-dense brine outfall that is the byproduct of all desalination processes. By better understanding the features of these outfalls, one can design a system that dilutes the brine effluent enough to pose little risk to sea life.

The main outcomes of the work performed were that the students were provided with international research experience, inluding the cultural exposure and training in advanced research methods. We two undergraduate students produced an undergraduate thesis at the host institution, and the graduate student worked towards finishing her Masters of Science thesis. The trip provided an opportunity to meet many international students and visit culturally significant locations in the EU and Europe.

RESEARCH ACTIVITIES AND ACCOMPLISHMENTS OF THE INTERNATIONAL COOPERATION

During this trip my primary research was to make preliminary investigations into the mixing and concentration of a dense plume in a crossflow and sloped environment. This setup is not uncommon for many desalination plants whose outfalls (waste discharges) are ejected into a river or the ocean. This experiment included setting up the experiment and making conclusions as to how best to continue the work using quantitative processes such as particle image velocimetry (PIV).

Among the results of this research is the observation that a crossflow leads to an asymmetrical spreading on the bottom not normal to coflow outfalls (Figure 1). The outfall in a crossflow has 4 distinct regions. First, the outfall leaves the nozzle as a turbulent jet, dominated by the velocity of the discharge. In a coflow, the cross section of the jet would be circular, but a coflow exerts a drag on the jet, causing an internal vorticity which makes the jet kidney-shaped. The next region is called the plume, in which the turbulence of the outfall causes it to develop eddies in its structure. The outfall becomes very large as the swirling eddies draw the surrounding water into the plume. This stage represents the majority of the dilution of the dense outfall ,dropping 90 percent or more in concentration of salt. The outfall then impinges on the bottom surface, spreading due to the negative buoyancy of the fluid. Two vortices lead the edges of the spreading plume, creating a M-shaped cross section in a coflow. In the cross-flow, the kidney shape of the jet and deflection of the plume seem to cause this M-shape to split, as the top part of the plume travels down the slope and the bottom spreads upward. From this point onward, the ambient effects of the experiment dominate, and the spreading outfall travels downstream with slower change.

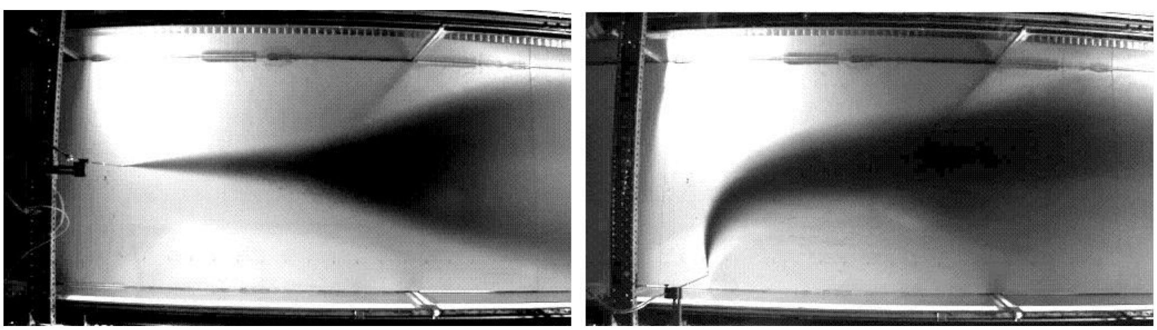

Figure 1. Comparison of coflow and crossflow orientations of dense plume, respectively. Despite the bottom sloping perpendicular to the flow, the coflow impingement spreading is symmetrical The crossflow spreading is comparatively asymmetrical In both cases the salinity of the plume decreases dramatically within several diameters of the outlet.

The experiment was done using a flume in the IfH using a simple two-camera array, looking down and from the side at the outfall. In addition to studying the general features of this specific flow case, the geometry of the plume was also measured and compared with the Density Plume module of the Cornell Mixing Zone Expert System (D-CORMIX). Generally speaking, the model measured the concentration of the outfall accurately, but could be improved with regards to predicting the trajectory of the plume. There have been fewer experiments done for the D-CORMIX model, so this data could provide some use improving the model.

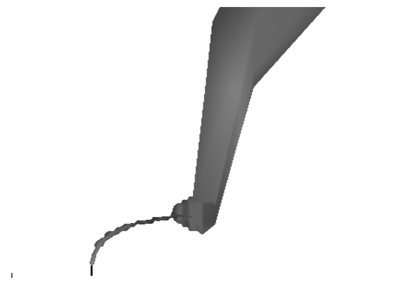

Figure 2. Output of D-CORMIX for a crossflow outfall. Comparison to Figure 1 reveals similarity of near field trajectory, and difference after impingement on bottom.

The near-field effects of the turbulent jet and plume and far-field effects of the bottom spreading take place on dramatically different length and time scales. Quantifying the near-field effects up to impingement would be relatively simple to do with laser induced flourescence (LIF), by shielding the area of interest from ambient light and managing the water and flourescent dye going into the flume properly. This results in three-dimensional concentration and velocity measurement inside the plume. The far-field effects could be very impractical to study with LIF because of the large length over which they are occuring, but have much less three-dimensional activity, so a two or one-dimensional method such as PIV or acoustic doppler velocimetry (ADV) could be more usable.

This research relates very well to the NSF award. The funding from the IREE allowed us work experience in a foreign exchange program, gaining technical elective credits but also experience in a different culture and language. Normally this experience is not possible in a regular engineering curriculum. While this research did not utilize PIV or LIF, valuable information was obtained for setting up a quantitative experiment studying the turbulent mixing processes and structure of a desalination plume.

The interaction between the researcher and the IfH was quite extensive. Even after summer, there is more collaborative work planned between Texas A&M and the IfH on desalination plumes. We researchers were invited to attend course lecture pertinent to turbulent plumes, and also attended meetings of the environmental fluid mechanics group. We were also given office and laboratory space in the building to work. This allowed interaction to be quick and comfortable.

BROADER IMPACTS OF THE INTERNATIONAL COOPERATION

Spending the summer in Germany was the best summer of my undergraduate career. We students thoroughly enjoyed exploring the stark contrast between modernism and tradition in Europe. Only in Europe can you so quickly and utterly change into a different environment and culture by crossing through the states and nations adjacent to each other. We visited much of the European Union's buildings and capitols, and were delighted by both the similarity of the people's friendship and the difference of the architecture and history.

The host institution was located in Karlsruhe, Germany, near the black forest in the south. Primarily a university town, Karlsruhe is small but quite modern. It was surreal to be there, where crowded city squares replaced highways for transporting professionals and workers to and from their offices. Due to the academic presence in Karlsruhe, the already-diverse German population was even further scrambled. All of western Europe was represented just in the Institute for Hydromechanics, and including people we met outside the Institute I would say the whole of Europe was present in Karlsruhe.

The IfH faculty was a standard unit working together, but each person—ourselves included—had unique traits that we learned to understand. Aside from personal characteristics, the researchers each had different educational backgrounds also. This expanded the scope of the IREE award by allowing us to learn from many more cultures than Germany. A lot of insight into my research came from guest scientists visiting the IfH. Particularly Robert Headland's lecture on a numerical prediction methods concerning New Orleans and

Joseph Lee from the University of Hong Kong attending the environmental fluid group meetings indirectly or directly influenced my thinking of my own experiment. Each person at the IfH added the knowledge of their unique locations, creating a diverse volume of academic resources.

The research done at the IfH is planned to continue both there and at Texas A&M. Dr. Socolofsky visits the Institute quite regularly. The research on dense desalination plumes that I assisted in is of particular interest to both Universities, and Kerri Whilden's work on vortices in tidal inlet flow will continue to be advanced and evolved, with insight from the experimental setup in Karlsruhe going towards building a tidal basin at A&M. This trip fostered the further interaction of two Universities and nations already in a close relationship.

Discussion and Summary

The IREE program sent two undergraduate students and one graduate student to conduct experiments on shallow tidal inlets, shallow forced vortices, and dense plumes. Through the research, I gained experience in environmental fluid mechanics, including dye visualization, data acquisition, image analysis, particle image velocimetry, and acoustic doppler velocimetry. I was able to collaborate with the two other students during the trip also, helping them complete research on drinking reservoir circulation and making progress towards the graduate student's Master of Science Thesis.

The interaction with the IfH through the IREE program allowed me to set up an experiment at the IfH and acquire valuable data on the features of dense plumes. This data allows for the development of future collaborative research between Texas A&M and the IfH. This trip also allowed me to gain experience in CORMIX and further the verification of its density plume module.

The IREE program represents a successful exchange between a foreign laboratory and the United States. The Institute for Hydromechanics was professional and diverse, and happy to work together on research. Altogether, the best practice for the IREE program is to choose institutions like the IfH that perform state of the art research while maintaining a high level of interaction with fellow researchers around the world.

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Brief Biographies of Researchers

John Bandas is an undergraduate student in the Coastal and Ocean Division of the Zachry Department of Civil Engineering at Texas A&M University at College Station, Texas. He is expecting to graduate in fall 2009 and is planning on pursuing a M.S. Degree in Naval Architecture and Marine Engineering.