TIM DIVETT

How do You Map a Von Karman Vortex Street and How do You Use One to Generate Electricity?

Swirling structures in calmly flowing water inspire a deep, primal sense of peace and well-being. At the same time, images of Poe's maelstrom in turbulent oceans inspire a sense of terror.[1] Throughout the duration of my PhD, modelling the flow through ocean channels full of tidal turbines, I experienced both of those feelings. The terror initially dominated, with failed simulations and time ticking by, while the former dominated as my work progressed and I found the beauty in the fluid structures I was simulating. There is something inherently soothing and beautiful about looking at movies of simulated ocean flow past structures of tidal turbines as the vortices swirl around each other and dance across the channel. In my work, this combined with the satisfaction of seeing this beauty emerge out of the mathematical equations that I solved using large computing clusters to generate these movies. I was also inspired by the thought that this work was contributing some small part to the effort to generate renewable energy from the ocean, reducing the impact of climate change and meeting our increased demand for energy.

The mathematical beauty in my work is involved in the equations that I use to describe the ocean flowing through a tidal channel full of turbines. These equations describe the balance of pressure built up along the length of the channel by the rise and fall of the tidal height, measured against the friction of tidal turbines in the channel and the friction with the ocean floor. The friction of the turbines imposed on the fast-flowing water results in the formation of von Karman vortex streets downstream of the turbines.

Figure 1. The wake downstream of a Marine Current Turbines Ltd tidal turbine, raised out of the water for maintenance. Source: "Frazer-Nash Irons SeaGen Wrinkle," *renews*, 5 March 2014, http://renews.biz/62085/frazer-nash-irons-seagen-wrinkle/ (accessed 23 July 2018).

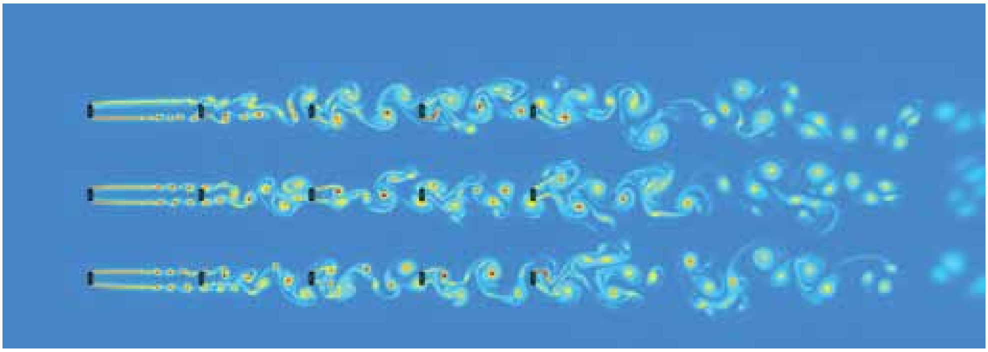

Figure 2. Looking down on the flow past an array of 15 turbines simulated by solving the equations describing fluid flow. Each black rectangle is a tidal turbine. Colour indicates rotation in the flow: the smoothly flowing blue water has no rotation, while red is strongly rotating water.

In my work it is tidal turbines that generate the discontinuity in the flow speed, leading to von Karman vortex streets in the wake downstream of the turbines. Tidal turbines are being developed around the world to harness the power of tidal flows to generate electricity from the pull of the moon and sun on Earth's oceans. Where this celestial pull on the oceans is focussed in narrow ocean channels like Cook Strait or Tory Channel in the Marlborough Sounds, the water is accelerated to speeds fast enough to power turbines. This flowing water drives a tidal turbine like Open Hydro or Marine Current Turbine Ltd's turbine (Figure 1) to generate renewable electricity similar to how wind turbines generate electricity. Also like wind turbines, to generate significant amounts of power we need to build farms of them.

A von Karman vortex street is the repeating pattern in parallel rows of swirling eddies that form in the wake of an obstruction in flowing fluid. These eddies or vortex structures develop downstream of any obstruction to the flow, like bridge piers or mussel farms. They also occur in nature where there is a sharp change in the speed of the flowing water due to a sudden change in water depth parallel to the flow direction, like the whirlpools at the Straits of Onaruto, Japan, or Poe's Maelstrom in Norway.[2]

In my work, the strongest vortex streets are downstream of the turbines at the left of Figure 2. On the top and bottom sides of the turbines in this figure the vortices rotate clockwise and counter-clockwise respectively, on either side of the slow-moving water directly downstream of the turbine. The water is slowed by friction with the turbines as they convert the energy in the moving water into electricity. Moving towards the right, the vortex street breaks down into less well-defined fluid structures as the wake from upstream turbines disturbs the flow onto downstream rows, leading to disturbed vortex streets and pairs of eddies that dance across the channel together further downstream.

The beauty and terror that eddies inspire in humanity is mirrored by the blessing and curse that these cause for engineers designing tidal turbines. While the fast-flowing water provides the power to drive the turbine, the turbulent vortices in the wake of a turbine put stress on downstream turbines by bending and twisting the blade as a vortex moves past the turbine. Understanding the balance between the power in the flow that can be captured by turbines and the impact on the natural flow by building these turbines was a fundamental part of my research.[3] I explored hundreds of different ways to arrange a farm of dozens to hundreds of turbines, searching for the best way to build a farm to capture the most power with the least environmental impact. A simulation of each farm layout generates a movie of the wake behind each turbine as the tide flows through the farm, then reverses back in the opposite direction when the tide changes. Figure 2 shows a snapshot from one of these movies as the tide flows from left to right past an array of 15 turbines in a channel similar to Tory Channel.

In my PhD, I explored how the fluid dynamics around these farms impact on how much power the farm can generate.[4] Building a single turbine in the channel generates some power by slowing the flow a little. Building a lot of turbines can potentially generate more electricity, but also slows the flow significantly more. At some point, adding another turbine to the farm slows the flow so much that less electricity is generated by adding that turbine, and the environmental impact is severe. This balance of power capture and flow reduction changes depending on how the turbines are positioned in a channel. I explored this balance by running computer simulations of the flow through channels with tidal turbine farms in them. I found that packing turbines close together in rows or fences on one side of the channel allows the best balance between generating more power with less overall slowing of the flow. This may help tidal energy developments overcome the hurdle of generating electricity from the ocean economically.

As the artist Megan Griffiths and I discussed how to represent these flow patterns in an art piece, we realised that we were both inspired by the von Karman vortex streets in the turbine wakes, as well as by the potential for tidal power to generate renewable power. We wanted to capture the movement in the simulation movies and the structure in the wake of a turbine. Using a fan to generate movement in the lightweight fabric was Megan's solution to this, while capturing the swirling beauty in a von Karman vortex street imprinted on the fabric. It also shows an analogy for the fan as the tidal turbine which generates this flow structure that is both beautiful and terrifying.

Tim Divett is a postdoctoral fellow in the Department of Physics, University of Otago. His PhD is on computational fluid dynamics modelling of flow around arrays of tidal power turbines.

1. EA Poe, Tales of Mystery, Imagination, & Humour; and Poems (London: H Vizetelly, 1852).
2. B Gjevik, H Moe and A Ommundsen, "Sources of the Maelstrom [6]," Nature, 388 (6645) (1997), 837-8, doi:10.1038/42159.
3. T Divett, R Vennell and C Stevens, "Optimization of Multiple Turbine Arrays in a Channel with Tidally Reversing Flow by Numerical Modelling with Adaptive Mesh," Philos. Trans. R. Soc. A Math. Eng. Sci, 371 (1985) (2013), doi:10.1098/rsta.2012.0251; T Divett, R Vennell and C Stevens, "Channel-scale Optimisation and Tuning of Large Tidal Turbine Arrays Using LES with Adaptive Mesh," Renewable Energy, 86 (2016), 1394-1405. doi:10.1016/j.renene.2015.09.048.
4. TA Divett, "Optimising Design of Large Tidal Energy Arrays in Channels: Layout and Turbine Tuning for Maximum Power Capture Using Large Eddy Simulations with Adaptive Mesh, " unpub. PhD diss. (University of Otago, 2014).

MEGAN GRIFFITHS

How Do You Map a Von Karman Vortex Street?

Physicist Tim Divett spends his time using powerful computers to solve the mathematical equations (which he describes as "beautiful") that describe fluid dynamics. In his presentation to possible artists last November, he showed the solutions to his equations as computer-generated visuals. These visuals were of eddies coming off turbine blades, which are called von Karman vortex streets. He also commented that he loved the colours of these visuals and was hoping to find an artist who also liked them.

The concept of tidal current-generated power is one that I am very interested in, given the amount of ocean surrounding New Zealand. This, and the wonderful visuals produced by Tim in his introductory presentation, immediately drew me towards his work.

Figure 1. Fabric Samples.
Photograph: Megan Griffiths.

At our first meeting, Tim gave me some of his work to read. While most of it was in language only another physicist could understand, sprinkled throughout were diagrams showing a variety of computer-generated von Karman vortex streets. He also gave me a couple of web addresses to have a look at actual tidal turbines at work.

My overwhelming first thought was to try and produce a work with movement to mimic the von Karman vortex street. That said, how to end up with such a work seemed like a huge if not impossible task.

I first looked at what kind of fabric I could use that would be light enough to move, sheer enough to see through and sturdy enough to work with. I tested a variety of chiffons and organzas. None had the combination I was looking for. A bit of brainstorming and looking though my collection of fibre art books set me off to look at some more unusual fabrics – fine interfacing Vlisofix, Mistyfuse, Lutradur and Bondaweb. Mistyfuse, Vlisofix and Bondaweb are all types of double-sided iron-on fusible webbing – mostly used in textile work to bond two pieces of fabric together. Lutradur is a non-woven polyester cloth similar to dressmakers' interfacing. It comes in several weights, the finest of which is almost transparent.

Further tests brought the choices down to Mistyfuse and Lutradur. Both had the attributes I was looking for – very fine, almost transparent yet not totally fragile, able to be painted or dyed easily, and lightweight enough to produce movement.

Figure 2. Testing paint on Lutradur and Mistyfuse. Photograph: Megan Griffiths

I tested both types of fabrics with a variety of paints and dyes in various strengths to see what the resultant colour would be and how well the fabric would 'take' it. In addition to this process, I also used a fan to see how each type of fabric moved in a breeze.

The final choice was Lutradur, and with 6m purchased and sent to me, I started on the project of colouring it. After cutting the fabric into three two-metre lengths, I laid out each piece separately on the table on top of lengths of silicone baking paper. Using the colours I had chosen, I painted each piece separately, mostly spraying the paint onto the fabric. The first piece I painted was the darkest – using the dye/paint at almost 1-1 strength, with water added to make the painting process easier. The following two pieces were painted at 1-2 and 1-3 strength, making each one slightly lighter than the previous example.

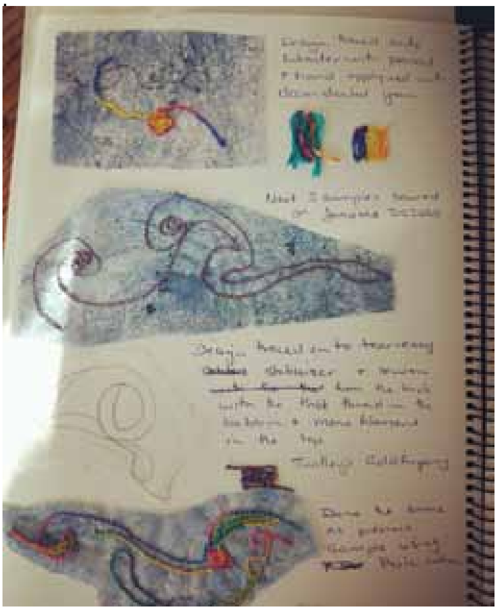

Figure 3. Trying to map a von Karman vortex street. Photograph: Megan Griffiths.

The next challenge was working out how to represent the von Karman vortex street in such a way that it could be seen through a layer of Lutradur, but still be light enough to blow in the breeze. My first ideas revolved around using some type of multi-coloured wool or thread appliquéd onto the Lutradur in the design I wanted. Some of the threads I used had potential, and some didn't, but being able to machine appliqué them onto the Lutradur using the bobbin appliqué technique had quite a few drawbacks, as well as making the fabric too heavy to float easily. I then tried needle-felting wool yarn and roving in the design I wanted. While I was surprised at how well the Lutradur stood up to this, the test pieces turned out much too unwieldy.

Another session of brainstorming brought the suggestion of using foil to create the design. The fine metallic foil is laid on a cellophane background. A design is placed on fabric using some form of glue medium – including Vlisofix, glue gun, PVA or specially formulated foil glue. Once the glue is in place and is almost dry, the foil is placed coloured side down onto the glue and rubbed until the foil comes off.

Figure 4a-d. (a) Enlarged pattern pinned out; (b) Covered with silicone paper; (c) Lutradur pinned on top; (d) Finished piece with complete foiling. Photographs: Megan Griffiths

I chose a rainbow foil as the best colour to use, and I made several samples to find out how best to use the glue. Applying the glue with a fine brush meant that enough glue stuck to the design for the foil to come off easily, while not adding much weight to the final piece.
The last piece of the puzzle was how to use Tim's von Karman vortex street design. The picture I was using showed the design at about 2cm high and about 15cm long. How then was that to be translated into a design 50cm high and 200cm long? Further discussions with Tim led him to do an enlargement on his computer and send it to me. After a couple of tries, I finally managed to enlarge it to the correct proportions for the size of my fabric.

I pinned the enlarged design to a table, covered it with silicone baking paper and pinned the middle of the three coloured Lutradur sheets on top. As the fabric was so see-through, it was easy to still see the pattern. I applied glue evenly but thinly, following the pattern and left until just tacky. The foil was then laid over the top of the glue and rubbed off. Because of the many angles of the design, the foiled area does not show the rigid stripes that are on the original foil.

Once this process was completed, I found a suitable fan and tested this with all three layers attached to the fan by hooks to find which was the best angle and speed for the fan, and the best placement option for the fabrics.

Once installed, the completed piece was everything I had first envisioned, and I was very happy to find out that Tim was also pleased with it.

Working with Tim opened a whole new field for me, and I found his input and suggestions helped me in forming my ideas for the finished piece. Tim talks about experiencing both the peace and well-being as well as the terror of the maelstrom as described in Edgar Allan Poe's writing during his

Figure 5. Installation piece. Photograph: Pam McKinlay.

work on his PhD. I felt similarly while working on this piece – the terror as something went wrong, and the peace each time I worked out part of the puzzle.

I look forward in the not-so-distant future to seeing some of Tim's work being showcased in our waterways.

Megan Griffiths graduated from the Dunedin School of Art in 2016 with an Honours degree in visual arts (textiles). Now in 2018 she has returned to the Dunedin School of Art to start work on her Master of Fine Arts. Megan has been working with textiles for more than 30 years.

1. Cotterill, Wendy. *Sponbonded Textile & Stitch*. Batsford, 2011.
2. Eckmeier, Karen. *Layered Waves: a Fresh New Way to Quilt*. The Quilted Lizard, 2009, pp 4-7.
3. Kahn, Sherrill. *Mixed-Media Class with Sherrill Kahn*. C & T Publishing, 2013, pp 22.
4. Midgelow-Marsden, Alysn. *Stitch, Fibre, Metal & Mixed Media*. Search Press, 2014.
5. Pacciani, Christina. "The Travelling Arlecchino Project." *Felt*, June 2012, pp. 36–37.
6. Pacciani, Christina. "The Travelling Arlecchino Project." *Felt*, Dec. 2012, pp. 35.
7. Shinn, Carol. *Freestyle Machine Embroidery: Techniques and Inspiration for Fiber Art*. Interweave, 2009, pp.134.
8. Smith, Sheila. *Felt Fabric Designs: a Recipe Book for Textile Artists*. Batsford, 2013, pp 35-37.
9. Smith, Sheila. *Felt to Stitch. Creative Felting for Textile Artists*. Batsford, 2014, pp 48,67.
10. Thittichai, Kim. *Hot Textiles: Inspiration and Techniques with Heat Tools*. Batsford, 2018.
11. Thorne, Dawn. *Transparency in Textiles*. Batsford, 2009.
12. Tristan, Julie, and Rachel Lombard. *How to Be Creative in Textile Art*. Batsford, 2011.
13. Triston, Julia, and Rachel Lombard. *How to Be Creative in Textile Art*. Batsford, 2011.