Building the Wind

The Open City is a city more open to the vicissitudes of climate and the meteorological. Rather than the conventional architectural strategy of omitting or ameliorating the weather, this paper looks at a design-research and building project over several years which attempts to incorporate the turbulent into the fabric of buildings and thereby to explore the potential atmospheric, perceptual and programmatic effects of such a strategy.

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SERRES ON TURBULENCE

In this paper the turbulent is seen not just as representative of the Meteorological but, building on the work of the French philosopher Michel Serres, as an "abstract machine"[1] of change --and, by extension creativity-- in multiple fields.

Serres is distinctly interested in the potential resonances across conventionally divided fields such as the arts and sciences or philosophy and myth and in this he searches for common patterns which are found across disciplines. One of the most significant for him is the turbulent. In his book *The Birth of Physics* he identifies the process of creativity as a transformation from the predictable and linear (defined as the laminar) through an initial swerve or deviation (the "clinamen") to the non-linear creativity of the multiplicity (turbulence) and finally to emergent steady states (the vortex)[2] . In his later book *Genesis* he continues this analysis with a description of turbulence as the key to the transformation from noise (chaos) to order[3] (and information) in the world.

> *"The angle [clinamen] . . . breaks the chain of violence, interrupts the reign of the same, invents the new reason and the new law, foedera naturae, en-genders nature, as it really is. The minimal angle of turbulence produces, here and there, the first spirals. It is literally the revolution. Or the first evolution towards something other than the same. Turbulence disturbs the chain. It troubles the flow of the identical, just as Venus disturbs Mars."* [4]

As if to back up Serres argument[5] the German theorist Theodor Schwenk traced this creativity of the turbulent through multiple branches of nature[6]. With a kind of obsessive zeal he demonstrates at multiple scales –from the inner ear to river deltas-- and across multiple spheres –from the biological to the hydrological to the mineral—how similar patterns and forms emerge from similar actions of turbulent flow. This may be what Serres was referring to with his identification of the "clinamen" or "swerve" as the root of all creativity. This is a move which he


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Figure 1: A drawing of turbulence in water by Leonardo da Vinci (public domain).

initially identifies in Lucretius' *De Rerum Naturae* but which he then observes as extending across multiple fields from the sciences to the arts[7].

For us it is Interesting that creativity is identified with the apparent chaotic state of turbulence and not the linear or stable conditions of the laminar or the vortex. This analysis resonates with our own fascination with the turbulent, especially its unpredictability and potential creativity which, along with its obviously fundamental relation to the processes of an increasingly out-of-equilibrium planetary atmosphere, make it, for us, a compelling phenomenon to study.

However rather than recreating illustrations of the results of this process in nature blown up to the scale of building we are more interested in the creative possibilities of the operation of the turbulent on the *material* of architecture following its own logics of design, description, assembly and even use. The intention here is not to achieve "bio-mimicry" but to strive for something maybe deeper –the conditions from which the patterns of the biological emerge.

In addition, as architecture, as-built, is situated within that very complex environment which we are simulating, the real atmospheric effects of the weather can combine with material variations to produce ever-changing, unpredictable and *dynamic* variations in spatial atmosphere.

TURBULENT SIMULATION

Recent developments in digital culture have allowed some of the wildness of nature to seep into the black boxes[8] on our desktops. In particular we are now able to simulate the complex, non-linear performance of fluids with increasing accuracy.

These new technologies potentially allow the opportunity to go beyond the fixed forms of classical physics to understand the world in new ways. As has been observed:

> *"For Serres, science – from geometry to Newtonian mechanics – has consistently chosen the path of Mars, seeking control and determinism. Only recently, with the 'rediscovery' of fluid mechanics and the new understanding of turbulence and emergence provided by the complexity sciences, has Venus returned…"*[9]

The new technologies of fluid simulation are of two basic types –with two very different purposes: The first (generally known as Computational Fluid Dynamics

–or CFD) is designed to simulate fluid dynamic systems in measurably accurate ways for engineering and technical design purposes (originally for machinery but increasingly for buildings too). The second type of simulation is intended to recreate the *visual effects* of fluid dynamics –primarily for animation purposes—without a focus on quantifiable "correctness".

Distinction between these two uses of simulation is important. The first use of simulation, for engineering purposes, is (conventionally) reflexive. That is simulating the performance of forms that have been created, perhaps with the purposes of fluid management in mind (an essential aspect of passive design) but generally without the use of simulation as a design tool or generator of architectural effects in itself. On the other hand the second use of simulation, for animation purposes, while technically not very accurate[10], is potentially more projective because of its engagement in simulating not just the performances of fluids but the relation between *material* and those fluid performances. Animators need to simulate the effects of wind or water flow on hair, fur, fabrics or particulates (eg. dust, snow) and, because of this, the tools they use create relations between the turbulent, non-linear simulation of fluids and the materials or objects they affect, in effect creating form or patterns which result from the turbulent.

It is primarily the latter use of simulation --as a creative tool-- that we are going to discuss in this paper. Unlike the essentially invisible effects of computational fluid dynamics these simulations are most interested in the visual –and thus material- impacts of fluid dynamics, producing *visible* effects of the turbulent. In some ways there are parallels between this process and the emergence of forms from turbulence in nature that Schwenk observed. However attempts at literally recreating this process would be counterproductive as they would promote a search for recognizable forms from nature, or, as is often the case, optimally efficient forms. On the contrary we are more interested in accepting the potential of such tools to generate the unforeseen, in other words to be creative.

The other thing which must be said at this point is that, while there is currently a clear distinction between engineering uses of fluid simulation and purely aesthetic uses, we do not rule out the possibility of their convergence at some future date and a commensurate synthesis between technical performance and visual effect.

The simulation tools mentioned above make some of the non-linear, "chaotic" patterns of fluids more accessible to us as designers. But how do we harness that wild energy in design? And, following Serres, is it capable of producing creative insights that go beyond the generation of novel forms? Is the intuition of the shape in the clouds --recognized by artists from da Vinci[11] to Olafur Eliasson[12]-- a tool which can be brought through design from an initial (fuzzy) insight to a final (perhaps blurry) building?

DIGITAL TECHNIQUE

Our understanding of space, starting in the Renaissance, has gradually become codified as a matrix of homogenous co-ordinates which can each be described neutrally --the x, y, z of Cartesian space. Indeed this is the basis of all of our digital tools to describe and understand space -GPS, GIS etc. Even apparently dynamic systems such as CFD, Weather Simulations etc. are built up from such subdivision and initial homogenization of space. However, through the activation of individual points within these simulations and the complex formulae of interaction between them, the multiplicitous non-linearity of atmospheric space re-emerges from the homogenized space of the digital.

Through the activation of the static points of Cartesian space into the dynamic vectors of fluid-dynamic space a transformation in our understanding of the nature of geometric organization takes place. Driven by an underlying abstract-machine of turbulence, points are let loose to become the vectors of a transformed space where a nebulous materiality supersedes the certainty of singular descriptive geometry.

A key problem in realizing the non-linear is the issue of description -how to represent inherently complex, infinitely varied patterns in a way that is legible, clear and most importantly for us as architects, buildable or makeable. Key to our strategy is the transformation of the Cartesian grid into a dynamic vectorial grid and using the efficiency of vectorial description (point and direction only) to act as the basis of the descriptive system. In this we are assisted greatly by the inherent architecture of CAD and animation softwares which, no matter now complex their outputs are based on point-coordinate systems, usually augmented either through the addition of vectorial information (e.g. so-called "soft bodies") or mesh, pixel- or voxel-based information (e.g. Computational Fluid Dynamics, Finite Element Analysis etc.). Thus, despite the inherent apparent complexity of turbulent simulations their description can be an accumulation of a multiplicity of very simple co-ordinate/ directional data.

MATERIAL TECHNIQUE

The following section describes a series of research projects, design studios and built projects, carried out in in Europe and Taiwan, which explore these issues and their impact on design and making.

In most of the examples we will describe here –both built and unbuilt—the process of translation of the non-linear patterns of the turbulent into architecture is explored as a generator of novel tectonic and descriptive techniques. As mentioned above turbulent simulations are built up from multiplicities of very simple co-ordinate/ directional data. This insight means that, when it comes to material assemblies, components and their manipulations can be simple while giving a complex overall effect. The inherent simplicity of these underlying descriptions combines with their number to produce the non-linear complexity we observe as "turbulent". Simple variations -e.g. angle, color, length, bending-- combined together in enough quantity can, like the frames of a movie, appear like the continuously -and much more complexly varying- effects of nature.

SOLAR GRASS FIELD

The very first project in which this idea was pursued was a design for a solar installation for the 300 ft. long solid concrete south-facing wall of the US Department of Energy Headquarters in Washington DC.

Using one of nature's most profuse examples -grass- as our model, we proposed a vertical solar collector that interacts with the turbulence found on site to generate a constantly changing visual landscape. Our design took the form of hundreds of flexible solar "blades" attached at right-angles to a net in front of the existing wall, using springs which allow the blades to move easily. The solar blades incorporate the latest flexible photovoltaic technology[13] which can be very thin. This allows them to bend and flex while still generating electricity.

Incorporating real turbulent performance into the fabric of the building using a flexible component, the installation activates an otherwise dead urban space using the energy available in the atmosphere to drive a constantly changing choreography of building components. Here the individual component is released, to a certain degree, from its usual fixed connection to the building in order to allow each individual element to perform in its own way but to collectively combine to reveal the overall turbulent patterns of the wind on the building. Point of connection (in this case a spring) and Linear element (the strips of photovoltaic material) combine to approximate the finite element, point and vector based simulations of the computer and transfer these, and their effects into real space. The solar grass field uses the repetition of identical components in combination with variations in the microclimatic conditions of the site -in this case the real wind- to make the turbulence on the site apparent. However it depends on the real action of the wind and the use of many moving parts to create its ever-changing patterns and while this movement is compelling it does not have significant architectural impact. To borrow the critic Jeff Kipnis' term[14], it does not constitute a "re-origination" of the natural into architecture.

TEACHING

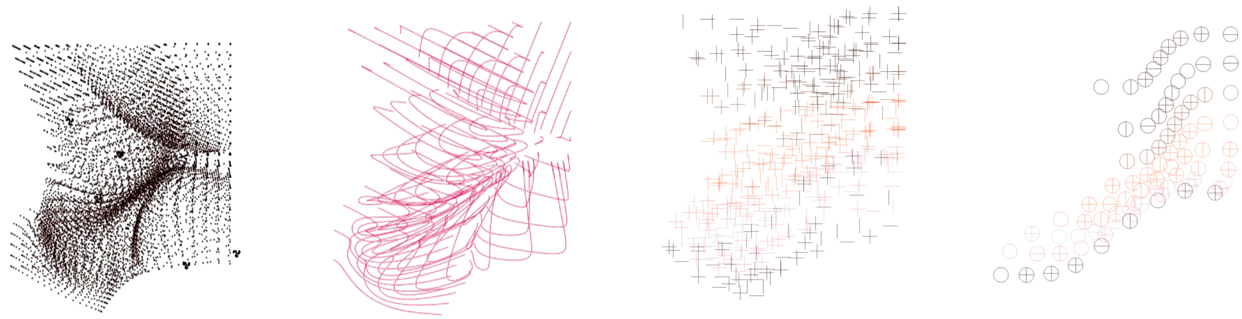
The potential for meteorological systems and their effects to generate novel architectural effects has been explored in a series of design studios beginning with the "Weather Unit" at the AA in London. In that Unit students researched weather systems and how they are understood and modelled by meteorologists (in many cases through the use of extremely sophisticated simulations). From this research students developed their own (less sophisticated but organizationally similar) simulation techniques which were used to understand both the organization and the effects of these natural phenomena.

BLIZZARD

For instance one student –Billy Choi- studied blizzards, particularly the phenomenon of "Saltation" which is the turbulent re-animation of already-fallen snow particles off the ground and back up into the air. This effect is produced by the local turbulence that occurs close to the ground as a result of boundary layer effects[15]. The student was interested not just in the physics and simulation of this effect but also its impact as a spatial atmosphere: an effect of immersion within an all-white, apparently limitless, non-oriented space which is at the same time open and private, perceptually isolated from the surrounding city or landscape but continuous with it.

Research into, and simulation of these kinds of dynamic, turbulent effects led to new organizational systems based on multiplicities of differentiated vectors rather than fixed co-ordinates. The second aspect of the research (conducted as part of the Technical Studies component of the course[16]) looked at the material potentials of this kind of turbulent organization. Using simple connectors distributed across the points of the turbulent field to organize the performance of flexible metal strips. This produces the resultant atmospheric effect of immersion in a field of dynamic material. Taking the perceptually isolating effects of the blizzard as a starting point this material system was developed into an urban intervention which provided, blurrily defined, greater or lesser degrees of privacy within the continuous space of the city.

In these projects relations between material, program and perception are questioned and reinterpreted through application of the meteorological, often turbulent, to the architectural.



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MAKING & BUILDING

Finally we look at some built examples which, through either tectonic organization or material transformation, incorporate the changing dynamics of the turbulent into their built fabrics. In the final two examples below progressive orientational variation and the simple material methodologies of achieving this (variable connectors or bends) are explored as means to produce not only turbulent visual effects but also architectural ideas. For instance, individual pieces and their manipulations can be quite simple but aggregated together –as is characteristic of building components—they can produce complex effects. This takes the emphasis away from complex patterns or components and uses the scale of building to *assemble* complexity.

This basic insight –that turbulent complexity can emerge from multiple simple manipulations—is also essential in developing efficient, relatively simple and (most importantly) economical fabrication and building methods. As each project develops -whether a studio project, an installation or a building-- methods must be developed to make it real and, ideally, these methods should be as simple and effective as possible in order to be economic and have a chance of being built.

BAMBOO FOREST HOUSE

Finally these issues were explored in the bamboo screen of a house in Taiwan. Here the goal was to introduce the dynamic of the turbulent into the fabric of the house and in the process reinterpret both a local vernacular (the protective screen common throughout Taiwan as a defense against Typhoons) and a local material (the currently underused but highly sustainable bamboo). To re-originate turbulence into the building in order to achieve *architectural* effects rather than just an illustration of the action of turbulence in nature.

The project which was relatively low-budget is located on a long narrow site in a densely built-up urban area with issues of privacy on three sides and a blank lot-line wall on the fourth side. To reduce energy consumption the house was designed to use a combination of cross-ventilation and buoyancy (stack effect) ventilation to provide passive cooling. And to use natural lighting to reduce dependency on electrical lighting as much as possible. Both these strategies demanded that the house be open to light and air at all levels. On the other hand the narrowness of the site and the close proximity of neighboring buildings made this approach problematic. To address this conflict a screen was proposed which would provide security in the event of extreme weather and privacy from the street and neighbors).

The privacy effect is actually increased by the undulation and varying angles of the bamboo which breaks up vision in ways which are difficult to assimilate --the

Figure 2: AA student Billy Choi's work showing documentation and development of turbulent pattern from the blizzard.

familiar moiré effect which is more effective than parallel vertical or horizontal elements would be.

Parametric modelling of the screen to allow variation in angle and density builds on the logic of gradually transforming vector information (point and direction), explored in earlier projects. This setup is used to manage the gradual, undulating transformation of the bamboo poles. And this organization eventually became the basis of description for the fabrication and construction of the screen itself using the logic of point positions and vectorial direction to specify the location and angle of each individual pole to the fabricator on site. The simplicity of this description method was very effective allowing the supervision of the fabrication and construction to be carried out largely remotely (from London to Taiwan).

In the end the billowing effect of the bamboo softens the edges of the otherwise orthogonal building and brings some of the dynamic effects of the meteorological into the building. But it also explores the potential for the turbulent to suggest new ways of organizing and assembling material and the potential advantage of non-linear organizations in creating architectural effects –in this case greater privacy.

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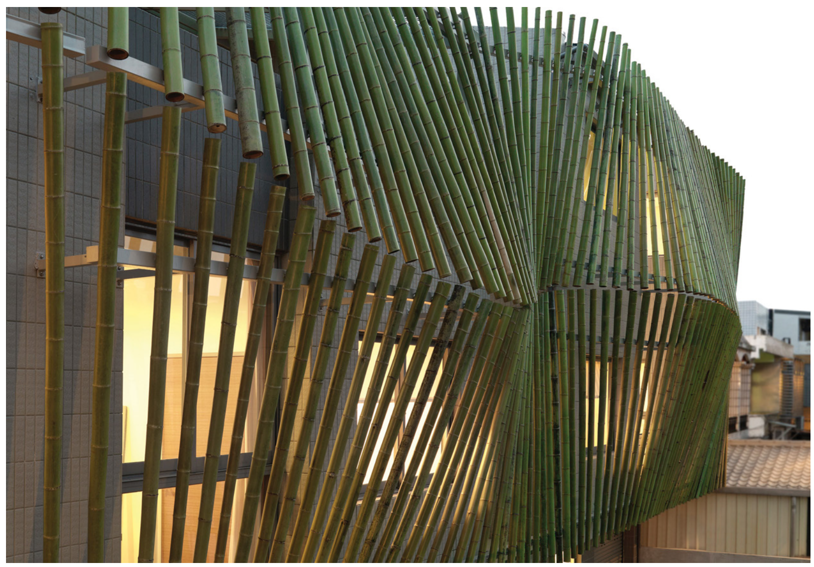
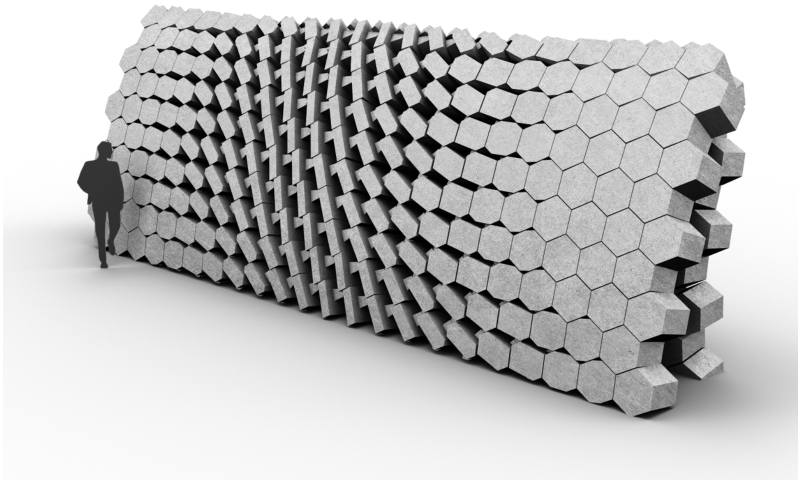


Figure 3: Exterior photograph of the Bamboo Forest House (photo by the author).

WIND TECTONICS

The northwest coast of Ireland is one of the windiest places in Europe with winds frequently exceeding Storm Force 10 (about 100 km/h). It is also a rocky and difficult landscape to farm. The traditional response to this was to clear the stones from fields and pile them up in stone walls around sometimes very small fields without the help of any cement or mortar. What is interesting is that these “dry” stone walls have stood for many years and usually with multiple small openings between the stones. Counter-intuitively instead of making the walls weaker these gaps actually help with their structural stability by allowing small amounts of wind to pass through the wall preventing the large differentials in pressure which most often cause walls in such locations to collapse.

Based on this insight the goal of this design-research project[17] was to develop a tectonic system for this location which could derive its stability from its openness, but which could also, using a component-based system which is more regular than the found stone walls, in some way express the dynamics of the wind forces pressing against it.



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We began with some studies, using simulation, of the relation between the form and openness of a notional wall and the resulting wind performance and/or air pressure around the wall. While formal variation produced somewhat predictable results it was the relationship between openness and air-pressure which began to fascinate us most.

From this research we developed a series of 12 components with variable openness and rotation. We used a hexagon rather than rectangular module because, of the 6 corners, only 3 need to be maintained in every module to give a structurally continuous (and triangulated) structure. This allows a higher openness to structural stability relationship than other modules. This cellular component then has 2 variables which control the openness of the module and its visual "rotation."

The resulting components were tested one type at a time using CFD simulation tools to study both the wind speed and the air pressure around the wall with different densities of openness. From these simulations we can see that as openness increases there is a dramatic reduction not just in wind speed but also turbulence on the leeward side of the wall. We also observe a gradual equalization of pressure between the two sides which would dramatically increase the structural stability of the wall. While there is some wind on the leeward side of the wall it would be significantly less than on the windward side and would be dramatically less than that caused by the turbulence resulting from a completely closed wall.

To counter the most destructive effects of the wind, the most open areas of wall would be situated at those points most exposed to the wind (again counter-intuitive but effective in improving the stability of the wall). As a result of the alignment between openness and "rotation" these areas would also have the most dynamic appearance. As a result a wall system which provides effective shelter and structural stability would reveal, through the gradually increasing rotation of the field of components, the intense turbulent drift of the wind in this isolated and exposed location. The visible effect of turbulence which we have been seeking in our projects would be aligned with –and would indeed ameliorate-- the actual turbulence of the atmosphere.

CONCLUSIONS

We have in this paper briefly described several different projects each of which could be gone into in considerably more detail, however the point we want to

Figure 4: A rendering of a partial section of the Wind Tectonics wall.

emphasize is the common goal that underlies this diversity of projects and how this common goal can facilitate a fertile cross-pollination of strategies from the digital to the material, from the geometric to perceptual variation. Multiple strategies and manifestations are united by a common, almost obsessive goal –to introduce the turbulent into architecture in a way that not only illustrates or recreates the turbulence seen in nature, but also tries to re-originate it as an architectural effect which influences organizational systems, tectonics, program and use in novel ways. These projects are just the beginning of a process of exploration which will hopefully be developed further.

This extended, difficult, sometimes tortuous but nevertheless rewarding process of transformation of an idea through research, design and experimentation into a built result demonstrates how a singular --if eccentric, or even obsessive-- concern can become manifest in different ways across multiple materialities, temporalities and scales eventually becoming manifest in building. In fact it talks as much about the obsessions which drive the movement from design to building as it does about the techniques of that process. In this way we hope that it tells us something about the process of design itself.

ENDNOTES

1. Although this is a term used by Deleuze & Guattari it can be seen as deeply influenced by Serres' work –as indicated by the multiple references to his work in the footnotes and supporting text of A *Thousand Plateaus.*

2. Serres, M. ([1977] 2000) *The Birth of Physics.* Trans. Jack Hawkes. Ed. David Webb New York: Clinamen Press.

3 Serres, M. ([1982] 1995) *Genesis*. Translated by Geneviève James and James Nielson, University of Michigan Press p. 109.

4. Serres, M. (2000) p. 110.

5. Schwenk's book was originally published in German in 1962 and in French in 1963 so Serres may have been aware of his work , though the controversial Schwenk (he was a proponent of "cosmic consciousness" and homeopathy) is unlikely to have been acknowledged.

6. Theodor Schwenk ([1962] 1996) *Sensitive Chaos: The Creation of Flowing Forms in Water and Air* Rudolf Steiner Press.

7. Serres, M. (2000).

8. "Black Box" is a term used by Serres to denote a device (organic or inorganic) which converts energy into information. The example he gives is the inner ear which converts vibrations of the air into meaningful information in the brain. In the way of working we are describing the unpredictable but nevertheless, rich outputs from dynamic simulation echo this definition. See Serres, M ([1985] 2008) *The Five Senses: A Philosophy of Mingled Bodies (I).* Trans. Margaret Sankey and Peter Cowley. London: Continuum.

9. Brown, Steven D. (2002) "Michel Serres Science, Translation and the Logic of the Parasite" in *Theory, Culture & Society* (SAGE, London, Thousand Oaks and New Delhi), Vol. 19(3): 1–27.

10. Kirkegaard, P.H.; Hougaard, M.& Stærdahl J.W. (2008) *DCE Technical Report No. 55: On Computational Fluid Dynamics Tools in Architectural Design* Aalborg University, Department of Civil Engineering ISSN 1901-726X.

11. Leonardo daVinci (1970) *The Notebooks of Leonardo da Vinci, Volume One,* ed. Jean Paul Richter, reissued New York: Dover.

12. See for instance Eliasson's "The morning small cloud series" from 2006 among other examples of his fascination with the formal and cultural effects of the meteorological.

13. For instance that manufactured by Solopower (solopower.com) though there are many others.

14. Kipnis, Jeffrey (2006) "Re-originating Diagrams", in *Peter Eisenman: Feints* Skira, Milan.

15. The boundary layer is the layer of any fluid close to its boundary (usually a containing vessel but in this case the surface of the ground) which is characterized by extreme turbulence as opposed to more laminar flow away from the boundary.

16. Our thanks to AA Technical Studies Coordinator Mike Weinstock for his invaluable assistance in this aspect of the course.

17. This research was generously supported by the Arts Council of Ireland and the Office of Public Works as part of the Kevin Kieran Research Award.