ABSTRACTS: AMSI-ANZIAM LECTURER 2015 – PROFESSOR MICHAEL SHELLEY

Technical Lecture 1
Mathematical Modeling and Analysis of Active Suspensions

Complex fluids that have a "bio-active" microstructure -- like suspensions of swimming bacteria or assemblies of immersed biopolymers and motor-proteins -- are important examples of so-called active matter. These internally driven fluids can have strange mechanical properties, and show persistent activity-driven flows and self-organization. I will show how first-principles PDE models are derived through reciprocal coupling of the "active stresses" generated by collective microscopic activity to the fluid's macroscopic flows. These PDEs have an interesting analytic structures and dynamics that agree qualitatively with experimental observations: they predict the transitions to flow instability and persistent mixing observed in bacterial suspensions, and for microtubule assemblies show the generation, propagation, and annihilation of disclination defects. I'll discuss how these models might be used to study yet more complex biophysical systems.

Technical Lecture 2
Microtubule and Motor-Protein Assemblies in Biology and Physics.

Many important processes in the cell are mediated by stiff microtubule biopolymers and active motor proteins moving upon them. This includes the transport of subcellular structures -- nuclei, chromosomes, organelles -- and the self-assembly, positioning, and maintenance of the mitotic spindle. I will discuss recent work in modeling and simulating some of these phenomena as multi-scale, geometrically complex problems in fluid/structure interactions. My focus will be on a large-scale computational model of how the pronuclear complex, with its hundreds of attendant microtubules, moves into "proper position" within an embryonic cell prior to cell division. Different assumptions on how the microtubules interact with the cell's cytoplasm (the fluidic interior) and its periphery give very different predictions for this dynamics.

Technical Lecture 3
The Mathematics of Swimming Collectives.

Swimming, or self-propulsion through a fluid, is done by algae, bacteria, birds, and whales. It even occurs inside of cells. Swimming becomes especially fascinating when it involves collectives -- like flocks and schools -- that interact through the fluid. I'll give several interesting examples, but focus on recent experiments that explore the interactions of many flapping flyers (think of geese in formation flight). They show that surprising collective effects -- bistable fast and slow "gears" and increased locomotive efficiency -- can occur due to the ability of a high-Reynolds number flow to store information on its past history of wing interactions. While simulations readily reproduce these observations, much reduced models involving peculiar delay differential equations and iterated maps of wing-vortex interactions give understanding and a surprisingly good accounting. They also show an unexpected connection to hydrodynamic analogs of pilot-wave theory.

Technical Lecture 4
Boundary integral methods for flows interacting with moving and flexible structures.

In either the inviscid limit of the Euler equations, or the viscously dominated limit of the Stokes equations, the determination of fluid flows can be reduced to solving singular integral equations on immersed structures and bounding surfaces. Further dimensional reduction is achieved using asymptotics when these structures are sheets or slender fibers. These reductions in dimension, and the convolutional second-kind structure of the integral equations, allows for very efficient and accurate simulations of complex fluid-structure interaction problems using solvers based on the Fast Multipole or related methods. These representations also give a natural setting for developing implicit time-stepping methods for the stiff dynamics of elastic structures moving in fluids. I'll discuss these integral formulations, their numerical treatment, and application to simulating structures moving in high-speed flows (flapping flags and flyers), and for resolving the complex interactions of many, possibly flexible, bodies moving in microscopic biological flows.

Public Lecture
Active and flexible bodies moving with(in) fluids

We are surrounded by structures that move and interact with a fluid -- a flag flaps in a stiff breeze, a bird flies overhead, or a microscopic bacterium swims across a droplet of water. The study of how such immersed bodies interact with fluids has a long and interesting history, and defines a class of "moving boundary problems" that are central to science. What makes such problems especially difficult, and so fascinating for an applied mathematician, is that the dynamics of body and fluid are intimately intertwined and must be treated in an integrated way. I will discuss fluid-structure interactions ranging those we can directly see, like flapping flags and flying birds -- to those we cannot, such as collective behaviours of swimming microbes and the transport of structures in biological cells. These examples will make clear the absolutely fundamental role that size plays in organizing our understanding.