Polymer Drag Reduction using the Slime of the Pacific Hagfish

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Abstract

Turbulent fluid flows are ubiquitous in the engineering world, and a simple, effective method of increasing the efficiency of such flows would therefore be extremely beneficial. It is well known that the addition of a very small amount (on the order of 10^{-3} kg/m^3) of a high molecular weight polymer can substantially decrease the frictional drag of a turbulent flow. The goal of the present research is to evaluate the turbulent drag reducing effectiveness of a specific biopolymer – the slime of the Pacific hagfish (*Eptatretus stouti*).

Methods To measure the drag reducing effectiveness of polymers experimentally, researchers typically measure changes in pressure drop in pipe flow. This measurement is most often made using pressure sensors along a long, straight tube through which fluid flow is driven by a pump. The frictional pressure drop is measured between two points along the tube for different values of driving pressure, and the resulting pressure drop is then compared with the pressure drop measured for the corresponding pure aqueous flow. The goal of measuring the pressure drop between two points in pipe flow is to indirectly measure the amount of energy that is frictionally dissipated by the flow turbulence between those two points. Pressure, however, is a very difficult flow property to measure; pressure can vary greatly along the flow cross-section, and pressure sensors are delicate, difficult to calibrate, and expensive. A far simpler method involves applying a known pressure gradient to a pipe and measuring the resulting mass flow rate of fluid. For purposes of this research, a simple, adaptable, low-cost apparatus for performing drag reduction experiments was designed and constructed. To avoid the necessity of measuring the magnitude of the applied pressure gradient, which can itself be somewhat problematic, the apparatus was designed around a gravity driven flow. The pressure gradient can then be easily calculated from knowledge of the geometry of the apparatus and simple hydrostatic fluid mechanics theory. The measurement of the mass flow rate through the system can be made directly using an electronic mass balance and a stopwatch. The flow exiting the test pipe is collected in a reservoir situated on top of the mass balance, and the mass of the reservoir is recorded as a function of time. The time rate of change of the mass (i.e. the slope of the data) is then the mass flow rate. These experiments will first be carried out with tap water and compared with predictions from the generally accepted Colebrook relationship for turbulent flow [2] to verify the reliability of the apparatus. For comparison with previous drag reduction measurements [7 and 8], experiments will then be carried out with dilute solutions (100 ppm by weight in both tap water and synthetic salt water) of Praestol 2500 and 2540 (polyacrylamides produced by Stockhausen Inc., nominally 0% and 40% hydrolyzed, respectively) at room temperature. Finally, the experiments will be carried out with dilute solutions (several concentrations in both tap water and synthetic salt water) of hagfish slime at room temperature. All results will be presented graphically as plots of friction factor against Reynolds number, where the friction factor f is the dimensionless pressure drop in the pipe and the Reynolds number Re is the dimensionless flow rate through the pipe.

A Control System for Growth of Carbon Nanotubes

David Held

Abstract Carbon nanotubes consist of molecular cylinders of graphite, capped at each end with half of a C_{60} molecule. Individual nanotubes exhibit extraordinary electric and thermal properties, as well as amazing stiffness, strength, and resilience. Thus far, these properties have only been realized for single tubes, and because today's poor bulk nanotube growth methods result in tangling of the nanotubes. Research indicates that more aligned fibers can be created by growing the nanotubes in a microreactor, by continuously growing and combining the nanotubes at a microscale. The goal of this thesis is to design a control system to test this idea, using a computer to control various actuators based on sensors and desired values. One such actuator is a power supply attached to a silicon resistor chip, which is used to heat up the system. Also, two mass flow controllers and a proportional valve control the gas flow rates of argon, methane, and helium, which must flow over a the substrate and catalyst to grow the nanotubes. The system actuators are controlled based on the readings of several sensors, including a thermocouple, two pressure transducers, and a flow meter, as well as a set of desired temperature and flow rate curves. Preliminary calculations indicate that the computer must accurately control the output actuators to within approximately 10% of the desired values. The computer program is also designed to be user-adaptable, so that an experimenter can change the desired temperature and flow rate curves to try to improve the results, or to use the system for a different chemical process.

Introduction Carbon nanotubes are a type of carbon fibers consisting of molecular cylinders of graphite. Each end of the cylinder is capped by six pentagonal rings, which is usually half of a C_{60} molecule. Nanotubes range in length from 30 nm to 4 um, with an outer diameter from 2.5 nm to 30 nm.[1] Figure 1 shows a carbon nanotubes, although practically, carbon nanotubes are much less ideal than that shown in the figure.

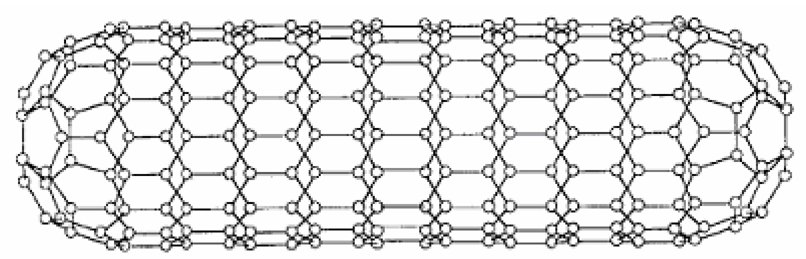

Figure 1: A carbon nanotube capped by one half of a C_60 molecule.

Nanotubes exhibit extraordinary properties which are useful for electronics. For instance, theory suggests that nanotubes can be conducting or insulating depending on their structure. Attempts to experimentally quantify the electric properties have been difficult. Still, preliminary experiments indicate that nanotubes will be a primary component in future nanoelectronic devices.

Similar problems have occurred in the testing of the mechanical properties, although tests indicate that nanotubes exhibit amazing stiffness, strength, and resilience. Individual carbon nanotubes have been shown to have a strength-to-weight ratio of 10-500 times that of steel, leading to possible future uses in nanotube-based gears and bearings.[2] Finally, carbon nanotubes have outstanding thermal properties, with a thermal conductivity of 2000-6000 W/m-K.[1] However, manufacturers have not yet developed a method to produce carbon nanotubes in large scales or at reasonable cost. The theoretically advantageous properties of carbon nanotubes have only been realized for single tubes. These properties are no longer present in a bundle of nanotubes, using today's poor bulk growth methods.

It is hypothesized that more aligned fibers can be created by growing the nanotubes in a microreactor rather than in a large reaction chamber, as is typical in most systems for growing carbon nanotubes. These carbon nanotubes can be grown and combined continuously at the microscale, which will ensure that the final product will be properly aligned. This technique of using microfabrication has been used with silicon-based technology to precisely control chemical reactions and produce bulk nanoparticles and quantum dots. However, this technique has not yet been applied to CNT growth. A control system is used to take advantage of this technique and precisely control the temperature and flow rates.

Mapping Crossing Myofiber Populations with Diffusion Spectrum Imaging in Simulated and Actual Muscular Tissues

Jason Liang

Abstract Tissue imaging using Nuclear Magnetic Resonance (NMR) is a rapidly growing area of research. One area of NMR categorized as diffusion-weighted imaging has received significant attention. A type of diffusion-weighted imaging titled Diffusion Tensor Imaging (DTI) has been used to image tissue fiber directionality in a variety of organs such and the tongue and the brain. While DTI data allows for the determination of a single principle fiber direction in a given voxel, it us unable to resolve more complex, non-parallel fiber patterns such as crossing or divergence. Diffusion Spectrum Imaging (DSI) expands on current methods of diffusion imaging as is believed to be able to resolve these complex fiber populations. The goal of this research is to validate DSI in simulated environments using both finite element model analysis as well as fabricated microfluidic structure analysis. If these studies are successful, the research will extend to include DSI of a mouse tongue.

Introduction The tongue is a unique and versatile muscular organ, which, in the course of normal speech and swallowing, assumes a large array of shapes, positions, and degrees of mechanical stiffness. It is generally believed that the structural basis of this behavior is the tissue's extensively interwoven myoarchitecture, in which muscle fibers are aligned along multiple axes. The determination of the tongue's complex myoarchitecture has long presented a challenge to students of structure-function relationships in muscular systems. Conventional tissue imaging methods, such as ultrasound, CT Scanning, and most forms of MRI, do not have the ability to determine details of internal structure. On the other hand, Nuclear Magnetic Resonance Imaging (NMR) of proton diffusivity has the capacity to infer fiber architecture by determining fiber direction. This is done by tracking molecular diffusion along muscle fibers. This type of NMR imaging falls under the category of diffusion-weighted imaging. A type of diffusion-weighted imaging termed diffusion tensor imaging (DTI), has been employed by Dr. Gilbert's laboratory to determine fiber orientation in excised sheep and cow tongues ex vivo[i,ii,iii] as well as other tissues, including the heart[iv,v,vi,vii,viii,ix] and brain. [x,xi,xii] DTI is generally able to resolve data to determine a principal fiber direction (principal eigenvector) and thus creates a 3-D anatomical map of a given tissue. While DTI is most accurate in analyzing fiber direction for regions of homogeneous myofiber alignment (all fibers are predominantly parallel at the scale of the individual voxel), it is limited for determining fiber alignment in the setting of more complex fiber patterns, such fiber crossing or divergence, and other nonparallel fiber alignments. As a result, a more general and robust diffusion method is needed, which is capable of tracking molecular diffusion in all directions, and thus more accurately quantify the orientation of complex fiber populations in biological tissues and other similar structures.

Building a Winning Team *A Motivational Model of the MIT Formula SAE Team*

Joseph Audette

Introduction Many people often incorrectly view motivation as a personality trait. In practice, inexperienced managers often label employees who lack motivation as lazy. Such a label assumes that an individual is always lazy or is consistently lacking in motivation. However, our knowledge of motivation tells us that this cannot be true. Rather, motivation is the result of the interaction of the individual and the situation. Individuals differ in their basic motivational drives, but not because of their personality. For example, a student may fall asleep after reading twenty minutes of their biology textbook, but read through an entire Stephen King novel in one day. In the case of this student the change in motivation is driven by the situation. Therefore, it is not fit to label this student as lazy, or unmotivated; because in fact motivation varies within this individual depending on the time and situation. An individual's motivation is dependent on the motivating factors within the situation. In the workplace, managers often have leverage over their employees in the form of bonuses, promotions, employment termination, etc. In most cases this leverage is enough to get the job done. But what happens when managers do not have this leverage? How can this manager motivate his team to produce results? This thesis will develop a motivational model of the MIT Formula SAE (Society of Automotive Engineers) Team. The MIT Formula SAE (FSAE) Team is a volunteer operation in which students design and build a small racecar for competition. Because this is a volunteer project, the team manager does not have the normal motivating factors witnessed in the workplace. In developing an alternative motivational model, we can describe the team performance over the course of the year. This thesis will be written as a business-case in the hopes that future team managers can use this model as an example to improve the performance of their own volunteer projects.

Background Motivation can be loosely defined as the processes that accounts for an individual's intensity, direction, and persistence of effort toward attaining a goal. It is the team manager's job to produce results, and in order to produce results he/she must motivate the team to perform. Likewise, there has been significant attention within Management Theory given to the topic of motivation. Furthermore, since motivation differs for each individual and situation, motivational theories have been developed to address a number of variables. These "output variables" can be factors such as satisfaction, needs, turnover, etc. The MIT FSAE Motivational Model will address many of the variables described in traditional motivational theories. However, it is necessary to narrow our specific research in order to stay within the scope of this thesis. While there are countless traditional and contemporary theories on organizational motivation, this thesis will focus on developing a model based upon goal-setting theory. Clear and difficult goals consistently lead to higher levels of team productivity. In the case of MIT Formula SAE, where success is highly dependent on fulfilling a schedule, it is understandable that we will begin to develop our model based upon contemporary goal-setting motivational theory. As stated earlier, the MIT Formula SAE Team is a student-run organization in which students design and build a small formula-style racecar for competition each May in Detroit. While the competition began in 1981, MIT fielded its first entry in 2003, placing 97/132 teams. The team improved dramatically in 2004, scoring points in all events and earning a placing of 41/127. While the team attributes this success to improvements in the vehicle design, the competition continues to grow and intensify each year. Jim Cuseo, Chief Powertrain Engineer, stated "We built a competitive car [in 2004], but we did not have a competitive program." If 2005 is to be another successful year, the team must increase their effort level, which in turn means their motivation.