Tong Gao

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BIO SKETCH

Tong (Tony) Gao joined the Michigan State University faculty in August 2015 with joint appointments in the Department of Computational Mathematics, Science, and Engineering, and the Department of Mechanical Engineering.

Dr. Gao works on a diverse array of problems in fluid mechanics, biophysics and materials through modeling and simulation, with a particular focus on soft matter physics. The essence of his research is studying novel fluid mechanics of microstructures immersed in liquid, as well as how the microscale particle-particle interactions impact the macroscale material properties of passive and active complex fluids systems (bacterial suspensions, biofilament assemblies, etc.). Gao has also been developing and integrating numerical methods to resolve multiscale physics from discrete particles to continuous medium.

He received his B.S. and M.S. from the University of Science and Technology of China (Hefei). He obtained his Ph.D. in mechanical engineering from the University of Pennsylvania. Following the completion of his Ph.D., he took a postdoctoral position in the Applied Mathematics Laboratory of Courant Institute of Mathematical Sciences at New York University.

RESEARCH INTERESTS

Complex fluids; multiphase flows; fluid-structure interactions

WEBSITE

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CURRENT RESEARCH FOCUS

Complex fluids—the multi-component mixtures—often exhibit non-Newtonian behavior in response to external loading, due to constituents' material properties, local heterogeneity in microstructures, and particle-particle interactions. When the constituents are self-driven, systems can be spontaneously out of equilibrium, orchestrating cooperative actions across various length and time scales. To exploit the full benefits promised by complex fluids, one must understand how the microscopic interactions manifest themselves at macroscopic level. As elucidated in the following, we use both numerical and theoretical methods to study novel physics and material properties of complex fluids.

1. Dynamics and rheology of soft particle suspensions. Soft particles are commonly found in nature and engineering applications. Examples include red blood cells, fluid vesicles, and microgel particles. When placed in a fluid field, these particles can readily undergo large deformations to accommodate the hydrodynamic forces exerted by the fluid, and in turn have a significant impact on the macroscopic rheology. So far we have developed a novel Arbitrary-Lagrangian-Eularian finite element method moving-mesh technique to resolve the nonlinear fluid/elastic-structure interactions, particularly in the large-deformation regime (e.g., Figure 1). At vanishing Reynolds number, we have also developed an analytical "polarization" theory which extends the classical Eshelby theory of composite material into suspension mechanics. At present, we are studying novel single-particle behavior, as well as the rheological properties using both numerical simulations and theoretical predicions.

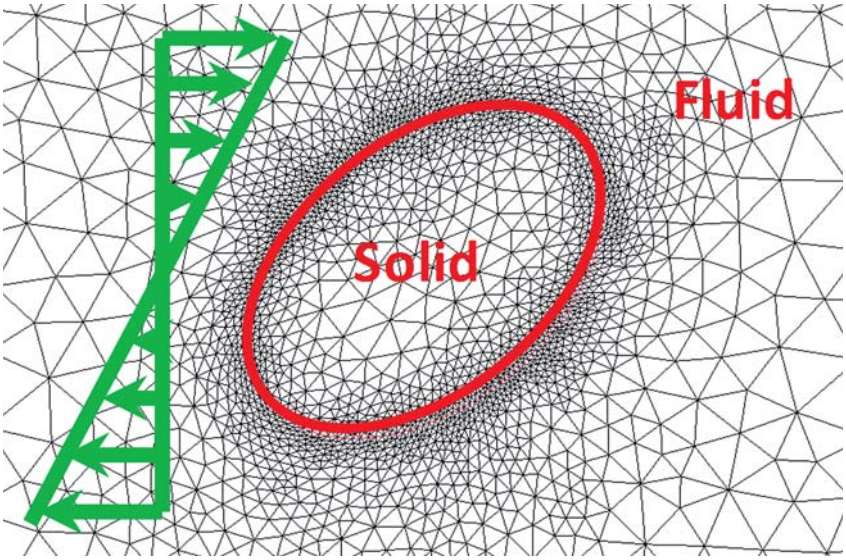

FIGURE 1. Elastic particle deforms into a 2-D elliptical shape in a shear flow.

2. Multiscale simulation of microtubule and motor protein assembly. Microtubules and motor-proteins are the building blocks of subcellular structures such as the mitotic spindle and the centrosomal microtubule array. They are ingredients in new "bioactive" liquid-crystalline fluids that are powered by ATP, and driven out of equilibrium by motor-protein activity to display complex flows and defect dynamics. As highlighted in Figure 2, we have developed a multiscale method: Brownian dynamics simulations of microtubule ensembles, driven by active crosslinks, are used to study microscopic organization and the stresses created by microtubule interactions. Then we design a Doi-Onsager rod theory that captures particle fluxes, and the hydrodynamic flows generated by particle-induced active stresses. We are able to identify the source of hydrodynamic instability, and capture characteristic length- and time-scales.

At present, we are integrating tools in both low-Reynolds number hydrodynamics and statistical mechanics to perform direct simulations for more complicated bio-networks. Our target is to use the successful understanding of in vitro systems to shed light on the material properties of in vivo subcellular structures, and construct accurate coarse-grained models to describe the complex bio-structures.

3. Microrheology of active suspensions. Dense suspensions of motile or driven rod-like particles (bacteria, synthetic swimmers, etc.) often exhibit coherent structures and collective motion. They have inspired the design of bioactive materials with novel active states and stress generation, and energy conversion to mechanical work. Though some bulk properties (e.g., viscosity) could be directly measured in experiment, it is very difficult to correlate such global quantities with the highly dynamic structures in the suspensions that are far from equilibrium.

As shown in Figure 3, we are performing thought experiments of microrheology measurement by driving spherical probe particles through the microswimmer suspensions. We use the low-Reynolds-number hydrodynamic methods (slender body theory, boundary integral method, Faxen's law, etc.), together with contact-mechanics models for short-range steric interactions. In addition, we use fast summation methods (e.g., smooth particle mesh Ewald method and fast multipole method) to solve many-body interactions, which significantly reduce the algorithmic complexity from $O(N^2)$ to $O(N)$.

4. Directed separation and assembly of macromolecules under electric fields. Fast and efficient particle manipulation is key to analytical chemistry, cell sorting, disease diagnostics, and drug development. There has been growing interests in utilizing electric fields to manipulate particles due to their inherent advantages such as non-intrusion, low cost, easy implementation, and favorable scaling with size. We have been studying electro-hydrodynamic interactions between small particles of various shapes, sizes, rigidities and dielectric properties, as well as the bulk properties of the suspension such as electrorheology. At present, we focus on design and optimization for experimental and biomedical devices where charged particles are transported in microfluidic devices.

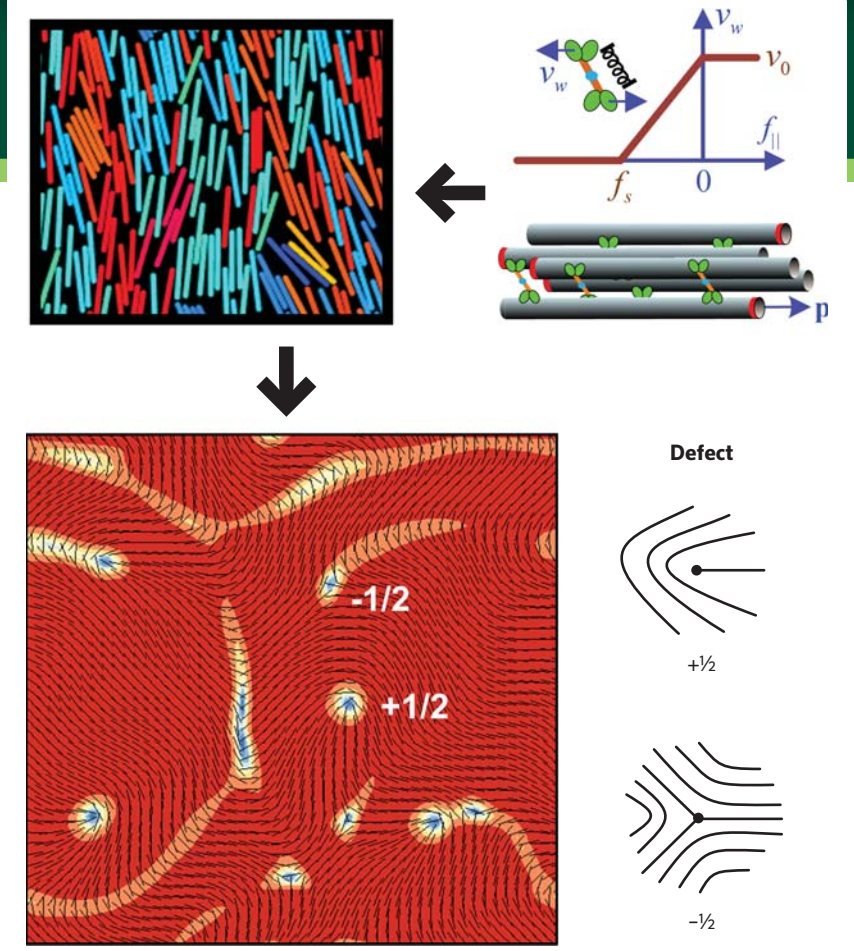

FIGURE 2. Schematic of multiscale simulation of microtubule and motor protein assembly from discrete particle simulation to continuum modeling.

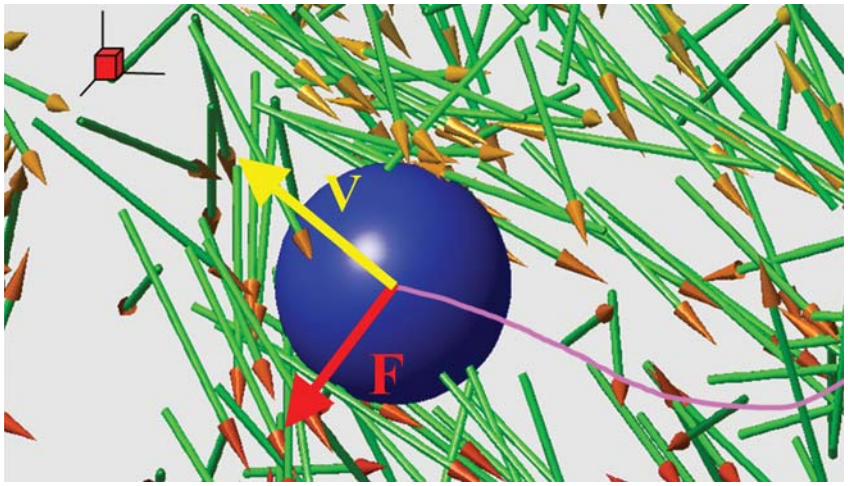

FIGURE 3. Microrheology measurement of microswimmer suspensions by dragging a spherical probe sphere.

RECENT PUBLICATIONS

T. Gao, R. Blackwell, M. A. Glaser, M.D. Betterton, M.J. Shelley, "Multiscale polar theory of microtubule and motor-protein assemblies," *Phys. Rev. Lett.* 114, 048101 (2015).

T. Gao, H.H. Hu, P. Ponte Castañeda, "Shape dynamics and rheology of soft elastic particles in a shear flow," *Phys. Rev. Lett.* 108, 058302 (2012).

T. Gao, H.H. Hu, P. Ponte Castañeda, "Rheology of a suspension of elastic particles in a viscous shear flow," *J. Fluid Mech.* 687, 209–237 (2011).

T. Gao, H.H. Hu, "Deformation of elastic particles in viscous shear flow," *J. Comput. Phys.* 228, 2132–2151 (2009).