# Research Statement

**Ralph C. Smith**

My research can be categorized as interdisciplinary with aspects of mathematical modeling, numerical analysis and control design directed at applications from various physical sciences. On one level, I view interdisciplinary research as a source of problems which are inherently important from a mathematical perspective. On a second level, I feel that applied mathematicians can play an important role as catalysts for large scale investigations which otherwise might not occur. The advantage afforded applied mathematicians in this latter role is that they can initiate and provide commonality through theory to investigations requiring components which are specialized and often disparate. Details regarding past, present and future directions which I am pursuing regarding these goals are categorized below.

**Model Development and Analysis:**

The first step in typical modeling investigations involves the in-depth study of the physics underlying the system under consideration. PDE models which incorporate the physics are then developed and considered in the context of associated infinite dimensional parameter estimation and control formulations. The analysis includes the determination of criteria which yield model and control system well-posedness as well as convergence criteria for numerical methods. Finally, the scope and accuracy of models are tested through validation experiments.

One aspect of my past work in this area was motivated by the problem of modeling structural acoustic systems with the goal of controlling structure-borne noise. This work was initiated while I was a postdoc in residence at the Institute for Computer Applications in Science and Engineering (ICASE) working with H.T. Banks, North Carolina State University (NCSU). Validation experiments were performed in collaboration with engineers in the Acoustics Division, NASA Langley Research Center. Due to inherent coupling dictated by the physics in the models, numerous mathematical issues concerning model well-posedness, numerical approximation and control formulation required investigation. This led to substantial analysis on our part, and initiated investigations by several independent groups on theoretical issues concerning these coupled models.

A substantial component of my current research program involves characterization and control issues concerning nonlinear smart material actuators and sensors. An example is the magnetostrictive material Terfenol which has been shown experimentally advantageous in many applications but is not fully utilized due to unmodeled dynamics. As a mathematician, I was able to formulate the broad modeling and control problem to be considered but lacked the experimental facilities and expertise in micromagnetic theory to provide necessary details. Through subsequent collaboration with David Jiles, Ames Laboratory, and Alison Flatau and her students, Department of Aerospace Engineering and Engineering Mechanics (AEEM), however, we have made substantial progress on the problem and have outlined a detailed future plan of investigation. From a purely mathematical perspective, the consideration of this general problem has led to specific investigations concerning nonlinear control dynamics and related issues. From the perspective of general science, the coordination of this interdisciplinary investigation has increased the utility of these materials.

A large component of my future investigations concerning the modeling of physical systems will be pursued in a similar manner. My current research program on magnetostrictive materials will extend for 1-2 years while more general investigations of electromagnetic phenomena and their utilization in control systems could extend for 5-10 years. My current and future research on structural acoustic, fluid/structure, and other coupled phenomena is focused on systems having nonlinear components, with various aspects to be investigated in collaboration with H.T. Banks, NCSU.

My perception regarding interdisciplinary collaborative efforts between physical scientists, such as physicists and engineers, is that investigations are occasionally hampered by the actual commonality between areas. For example, the groups will often redefine each other's problems rather than advance the general science. One of my goals as an applied mathematician is to provide the commonality necessary for advancing the science through interdisciplinary research without being perceived as a threat by component groups.

**Numerical Methods:**

The numerical approximation component of my research program is usually motivated by the necessity of providing algorithms for simulation, parameter estimation and controller design. Such methods are designed to utilize underlying physics whenever possible and to be commensurate with data collection techniques when validation experiments are performed. The systems under consideration are often large scale and efficiency is crucial to eventual implementation.

This component of past research has centered on the development of numerical methods for structural and structural acoustic systems. In addition to convergence analysis, issues of concern have included the maintenance of stability bounds in weakly damped systems, avoidance of locking phenomena in structural models, and real-time implementation for control design. This research has included the direction of Ricardo del Rosario, ISU and NCSU, on the development of approximation and control methods for thin shell applications.

The numerical problems which I am currently investigating are also motivated by the necessity for discretizing physical models, and I will continue in this direction in the future. In addition to algorithm development, this component includes various aspects of numerical analysis. For example, Ricardo del Rosario and I are currently completing the details regarding convergence analysis for a method we developed for shell applications. Another aspect of my current research in this area is being conducted in collaboration with Matthias Heinkenschloss, Rice University, and is directed toward the development of optimization methods for smart material systems.

**Control Design:**

The consideration of control issues is often the underlying motivation for my research into a given area but is typically the last component considered because it draws upon previous modeling and numerical results. My past research has centered on the development of infinite and finite dimension control methods for linear smart material systems with several components investigated in collaboration with H.T. Banks, NCSU, and Yun Wang, Brooks Air Force Base. I also directed Michael Demetriou, NCSU, on aspects concerning the numerical implementation of robust control methods for fully coupled structural acoustic systems. The culmination of this past research was the numerical implementation of control methods for structural acoustic systems and the real-time experimental implementation of a structural controller in the Acoustics Division, NASA Langley Research Center.

My current research in this area is centered on the development and numerical implementation of control laws for nonlinear actuators (e.g., Terfenol transducers). This is closely related to my previously mentioned research on modeling techniques for such materials and contains many of the same interdisciplinary aspects. For example, control requirements are being formulated in collaboration with Alison Flatau, AEEM, and she will play a fundamental role in the experimental implementation of the methods. While initial numerical results have demonstrated the efficacy of a preliminary nonlinear control method for Terfenol transducers, numerous theoretical and implementation issues remain to be resolved. Research concerning these issues, along with investigations concerning broader control problems pertaining to nonlinear actuators and systems, is projected for the next 5-10 years.