The John F. and Joan M. Calder Professor in Mechanical Engineering has been a blessing to the growth of my research and to student development. The activities and accomplishments of the Microfluidic and Interfacial Transport (MnIT) Lab for the last year are summarized here.

The Numbers

Numbers are important in academia as a measure of productivity even though these are an incomplete picture of teaching, scholarship, and service. Nevertheless, during the 23-24 academic year:

- 6 journal publications;
  - 1 in review
  - 3 additional manuscripts to be submitted by September
- 2 textbooks
  - MEEM 2911 – ME Practice 2
  - Engineering Thermodynamics with Merle Potter (continuing story)
- 1 Invitation to present at the National Academy of Science, Engineering, and Medicine (NASEM)
- 6 conference proceedings
- 3 conference talks (no paper)
- 3 current PhD students; one finishing in August
- 1 postdoc
- 1 undergraduate researcher
- 3 PhD committees
- 3 proposals; 1 funded, 2 declined
- > 161 citations in 2023 and 2024 (google scholar)
- 18 h-index (cumulative, google scholar)
- 39 i10-index (cumulative, google scholar)

Heat and Mass Transport in PEM Fuel Cells

The modeling approach used to predict reactant, water, and heat transport in fuel cell catalyst layers utilizes three independent, inter-connected networks for a fuel cell electrode. The "solid-phase" network captures electrical and thermal transport. The "pore-phase" network captures oxygen and water transport. And the third network is the "ionomer phase" that captures proton and water transport. It is the ionomer phase network that is the new addition and where the most interest lies. This work, particularly the ionomer network, is part of a PhD student's dissertation research. We have an industrial partner with which a DOE proposal has been submitted (July 2023 - proposal declined) that would extend this effort to heavy duty vehicles. There have been many collaborators on this research over the last 12 years. Recent relevant publications and presentations include:

- Shahriar Alam and Jeffrey S Allen. Capturing the Microstructural Complexities of PEMFC Catalyst Layers and Local Transports Therein Using Network Modeling Approach. *ECS Meeting Abstracts*, MA2023-02(37):1715, dec 2023
- K. Alofari, A. Asthana, A. Haug, and J. S. Allen. Dispersed Nanostructured Thin Film (dNSTF) Catalyst Layer. In Ezequiel F. Médici and Alejandro D. Otero, editors, *Album of Porous Media: Structure and Dynamics*, chapter Album of Porous Media: Structure and Dynamics, page 13. Springer, 2023. ISBN 978-3031237997

In October 2023, I was invited to participated in a meeting with the International Energy Agency (IEA) Task 37 Fuel Cell Modeling Annex at the Electrochemical Society (ECS) meeting that was held in Stockholm, Sweden.

Fundamental Studies of Evaporation & Condensation

A significant activity involves experiments and modeling of evaporation and condensation. The modeling effort includes CFD, kinetic theory, and development of evolution equations. This research also includes phase change of cryogenic hydrogen and methane. Over the last two years, this work has been funded by two NASA grants that were completed in 2021. An NSF/CASIS grant, with collaboration with U. Washington, for development of an experiment on-board the International Space Station was awarded in 2022 that will investigate instabilities of evaporating liquid surfaces. We are working with UW on development of the space flight hardware and an innovative approach to predicting transitions in fluid instabilities. We were awarded a NASA grant in October 2023 to develop a new method for capturing microscale physics at a liquid-vapor surface in enormous containers; i.e., orbiting cryogenic depots for refueling space craft. There are many collaborations on this research, including NIST, U. Washington, U. Cincinnati, NASA, and CWRU. Recent relevant publications and presentations include:

- Kishan Bellur and Jeffrey S Allen. A cryogenic neutron imaging experiment to address long standing discrepancies in evaporation modeling. In *9th Thermal and Fluids Engineering Conference*, number TFEC-2024-52559. ASTFE, 2024
- Unmeelan Chakrabarti, Ayaaz Yasin, Kishan Bellur, and Jeffrey S Allen. An investigation of phase change induced marangoni dominated flow patterns using the constrained vapor bubble data from iss experiments. *Frontiers in Space Technologies*, 4:1263496, 2023
- Kishan Bellur, Ezequiel Médici, James C. Hermanson, Chang Kyoung Choi, and Jeffrey S. Allen. Modeling Liquid-Vapor Phase Change Experiments: Cryogenic Hydrogen and Methane. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, 675:131932, 2023
- J.C. Gonzalez-Pons, J.C. Hermanson, and J.S. Allen. Heat transfer and convective structure of evaporating films under pressure-modulated conditions. *International Journal of Thermofluids*, 19:100381, 2023

Modeling Ex-situ Resource Utilization (ISRU)

I have a productive collaboration with Paul van Susante (Assistant Professor in MEEM) who is leading the effort at Michigan Tech in the area of detecting and extracting water on the Moon and Mars. I have been helping with thermal modeling in lunar regolith and Martian gypsum deposits. This work has been funded through multiple NASA grants. Recent relevant publications and presentations include:

- Travis Wavrunek, George B. Johnson, Paul J. van Susante, Ellie Zimmermann, Ben Wiegand, Mason Krause, Mason Rajan, Jeffrey Allen, and Timothy Eisele. *Method for Quantifying Lunar Polar Volatiles in Regolith and the Development of a Thermal Model.* 2023
- George Johnson, Travis Wavrunek, Anurag Rajan, Paul J van Susante, Timothy Eisele, and Jeffrey S Allen. Method for Thermal Modeling and Volatile Measurement of Lunar Regolith. In *Earth and Space 2022*, pages 273–280. American Society of Civil Engineers (ASCE), 2023

Nanoparticle Thermophoresis

Phase-change materials (PCM) are used to store thermal energy. A typical example is storing heat from a solar thermal collector in a fluid that can be circulated through a building at night. Phase change materials store an additional quantity of heat (latent heat). A limitation on the use of PCMs for thermal energy storage (TES) is that after repeated phase change cycles of charging and discharging, they may undergo supercooling. Supercooling is the metastable state in which the liquid does not freeze despite going below its freezing temperature. This results in the the lost

heat which can not be recovered and leads to an unstable system due to the unpredictability in the crystallization temperature. Supercooling can lead to PCM undergoing density change during phase change process which results in the changes in volume and it can rupture the walls of the container. Supercooling may be catastrophic in intensive care units or food preservation industries. Supercooling has been named by Department of Energy program managers as one of the "Grand Challenges" in energy storage. Using a non-equilibrium thermodyamics approach, we are able to provide plausible explanations to the contradictions in published experimental data.

- Udit Sharma and Jeffrey S. Allen. Modellig Thermophoresis in Nanofluids. In *9th Thermal and Fluids Engineering Conference (TFEC)*, number TFEC-2024-50984, Oregon State University, OR, April 2024. American Society of Thermal and Fluids Engineers (ASTFE)
- Udit Sharma and Jeffrey S Allen. Thermophoresis in nanoparticle loaded phase change material. In *ASME Summer Heat Transfer Conference*, number SHTC2023-108682. ASME, July 10-12 2023

Two-Phase Flow in Porous Media

A novel analytical model for predicting trapped saturation of a fluid in porous media has been developed and validated against published experimental data. The manuscript cited below was submitted last fall and has gone through the initial round of reviews.

- Karrar T. Alofari, Ezequiel F. Médici, and Jeffrey S Allen. Prediction of Trapped Saturation in Porous Media as a Function of Capillary Number using a New Scaling of the Saturation Gradient of an Immiscible Fluid-Fluid Front. *Interpore Journal*, in review, 2024

Education & Assessment

This work builds on the department's digital engineering initiative. Prof. Aneet Narendranath is leading the effort to use natural language processing to assess student performance and achievement. Recent relevant publications and presentations include:

- Aneet D. Narendranath and Jeffrey S. Allen. Automated text analysis of reflective essays to quantify the impact of the modification of a mechanical engineering course. *Journal of STEM Education: Innovations and Research*, 24(3):6–13, 2023

Teaching

During the Spring 2024 semester I taught a new course on Nuclear Power and Propulsion. The course covered the fundamentals of nuclear physics, nuclear reactors, electrical power production, marine propulsion, radioisotope generators, and nuclear rockets. I have had several students ask if was planning to teach this course again. The earliest I would offer this course again is the 2025-2026 academic year.

During the Fall 2023 semester, several MEEM faculty (Odegard, King, van Susante, Tajiri, Brueshaber, Parker, Allen) put together a proposal for a Bachelors of Science in Aerospace Engineering. This degree program heavily emphasizes Space Engineering while keeping full coverage of Aeronautical Engineering. The BSAE program leverages much of the BSME program to minimize the amount of new resources needed. The BSAE program will have extensive hands-on engineering practice courses. The Senate approved the proposal in April 2024 with a planned start date of Fall 2025. As of this writing, we are still waiting on the Provost to approve the program.

As part of this new degree program, the department name will change this fall to Mechanical and Aerospace Engineering.

Professional Service

One of the advantages of holding the Calder Chair is the recognition by the external community. In 2020 I was asked to participated in a NASA workshop to help define the future of the microgravity fluid physics program. This was followed in 2021 with my invitation to participate in two survey reports submitted to the National Academy of Engineering for their 2023 Decadal Report to NASA. The Decadal Report is issued every 10 years and provides a roadmap for NASA's research priorities.

In October 2023, I was invited to participated in a meeting with the International Energy Agency (IEA) Task 37 Fuel Cell Modeling Annex at the Electrochemical Society (ECS) meeting that was held in Stockholm, Sweden.

In March 2024, I was invited to the speak with the Committee on Biological and Physical Sciences in Space (CBPSS) at the National Academy of Science, Engineering, and Medicine during Space Science Week 2024 (March 20). The committee asked for me to present my perspectives on thermal-fluid physics in microgravity and its broader applications to space exploration.

I routinely serve as a reviewer for manuscript submissions to 5 or 6 journals and for NSF and NASA proposals. I am currently a member of the National Institute of Standards and Technology (NIST) Beam Time Allocation Committee. This committee makes recommendations on how much time researchers are allocated in the NIST Center for Neutron Research.

Associate Chair, Director of Undergraduate Studies

As the department Associate Chair, Director of Undergraduate Studies I chair the MEEM Curriculum Committee, MEEM Assessment Committee, MEEM Undergraduate Workstream Committee, MEEM Lab and Safety Committee, serve as the faculty advisor for the student chapter of ASME, and serve as the department liaison to the Mechanical Engineering Student Advisory Committee (MESAC). This last year included a significant effort towards ABET Accreditation and development of Bachelors of Science in Aerospace Engineering.