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 two academic year is 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 2021-2023 academic years:

Publications/Presentations:

- 11 journal publications; one awarded "Best Cryogenics Paper of 2022" by journal editors
  plus 1 currently in review and 1 in press
  plus 5 manuscripts that will be submitted by September
- 5 peer-reviewed conference proceedings; 3 conference talks (abstract only); 1 invited seminar
- 2 National Academy of Engineering Survey Papers
- $>$ 220 citations from Fall 2021 through Spring 2023 (google scholar)
- h-index: 18 (cumulative, google scholar)
- i10-index: 38 (cumulative, google scholar)

Students/Postdocs:

- 1 current postdoc
- 4 current PhD students; one is an online PhD student
  plus 1 PhD who graduated 8/2022
- 2 PhD committees
- 1 undergraduate researcher
- former PhD student and postdoc an Assistant Professor position at University of Cincinnati (2021)

Proposals:

- 6 proposals; 2 funded, 2 pending, 2 declined

Other:

- elected Fellow of the American Society of Mechanical Engineers in 2021

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) 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:

- K. Alofari, A. Asthana, A. Haug, and J. S. Allen. Dispersed Nanostructured Thin Film (dNSTF) Catalyst Layer. *Album of Porous Media: Structure and Dynamics*, E. F. Médici and A. D. Otero, eds., page 13. Springer, 2023
- J. Liu, et al. Coupled continuum and network model framework to study catalyst layers of polymer electrolyte fuel cells. *International Journal of Hydrogen Energy*, **47**(40):17749–17761, 2022

- S. Alam, E. Médici, K. Tajiri, and J. S Allen. Predicting local transport phenomena of pemfc catalyst layers using a network approach. *242nd ECS Meeting*, **39**, 1371–1371, Atlanta, GA, October 9-13, 2022
- K. T. Alofari, E. Médici, K. Tajiri, and J. S. Allen. Ionomer films impact on the structure, flow regime, and the wettability of the catalyst layer of PEMFC. *European Fuel Cell 2021 (EFC21)*, **334**:04019, 2022
- K. T. Alofari, E. Médici, K. Tajiri, and J. S. Allen. Humidification impact on mass transport in cathode catalyst layers of proton exchange membrane fuel cells. *240th ECS Meeting*, **46**: 1844, Orlando, FL, October 10-14, 2021

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. And we have just been informed (July 2023) that another NASA grant will be funded that will support a postdoc. The proposed work for this new grant is 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:

- U. Chakrabarti, A. Yasin, K. Bellur, and J. 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 - Reviews in Microgravity*, invited paper, manuscript in review, 2023
- K. Bellur, E. Médici, J. C. Hermanson, CK Choi, and J. S. Allen. Modeling Liquid-Vapor Phase Change Experiments: Cryogenic Hydrogen and Methane. *Colloids & Surfaces A*, **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
- K. Bellur, E. Médici, J. C. Hermanson, CK Choi, and J. S. Allen. Neutron imaging of evaporation/condensation in cryogenic propellants: an accommodation coefficient study. *APS Division of Fluid Dynamics 75th Annual Meeting*, Indianapolis, IN, November 20-22, 2022
- K. Bellur, E. F. Médici, et al. Results from neutron imaging phase change experiments with LH2 and LCH4. *Cryogenics*, **125**:103517, 2022 [**selected by editors as Best Cryogenics Paper of 2022**]
- K. Bellur, E. F. Médici, et al. Data from cryo-neutron phase change experiments with LH2 and LCH4. *Data in Brief*, **43**:108474, 2022
- S. Dasgupta, K. Bellur, and J. S. Allen. Exploring the inequality of evaporation and condensation coefficients based on iss experiments. *APS Division of Fluid Dynamics 75th Annual Meeting*, Indianapolis, IN, November 20-22, 2022
- K. Bellur, E. F. Médici, CK Choi, J. C. Hermanson, and J. S. Allen. Multiscale approach to model steady meniscus evaporation in a wetting fluid. *Phys. Rev. Fluids*, **5**:024001, 2020 [**Editor's Selection**]

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:

- G. Johnson, T. Wavrunek, A. Rajan, P. J. van Susante, T. Eisele, and J. S Allen. Method for thermal modeling and volatile measurement of lunar regolith. *Earth and Space 2022*, 273–280, 2022
- P. J. van Susante, J. S. Allen, et al. Identifying and quantifying Volatile Content and Geotechnical Properties in the Lunar PSRs. *ASCEND 2021*, Las Vegas, NV, October 23-25, 2021
- P. J. van Susante, J. S Allen, et al. Water extraction from rock gypsum on Mars. *Earth and Space 2021*, 653–659, 2021
- P. J. van Susante, J. S. Allen, et al. Research results and prototype development and testing for water extraction from polyhydrated sulphate rock on Mars. *ASCEND 2020*, virtual event, November 16-18, 2020

PCM Thermophoresis

This is a new research area for me. PCM is short for phase-change materials, which are used to store thermal energy. This work is focused on understanding the root cause of supercooling in PCM . We are using non-equilibrium thermodynamics to investigate whether or not the phenomena of thermophoresis could be responsible. We have a NASA graduate student proposal pending (submitted in February) that would fund the PhD student. Recent relevant publications and presentations include:

- U. Sharma and J. S Allen. Thermophoresis in nanoparticle loaded phase change material. *ASME Summer Heat Transfer Conference*, SHTC2023-108682, Washington, D.C. July 10-12, 2023
- U. Sharma and J. S. Allen. Role of Thermophoresis on Binary Phase Change Materials for Thermal Energy Storage. *7th Thermal and Fluids Engineering Conference*, TFEC-2022-40809, 357–363, Las Vegas, NV, May 15-18, 2022

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:

- A. D. Narendranath and J. S. Allen, "Automated Text Analysis of Reflective Essays to Quantify the Impact of the Modification of a Mechanical Engineering Course", *J. STEM Education: Innovations and Research*, in press, 2023.

Teaching

During the last two years I have served as an instructor and course coordinator for ME Practice 2, course coordinator for Introduction to Fluid Mechanics & Heat Transfer, and as a Primary Advisor for Senior Capstone Design.

Professional Service

One of the advantages of holding the Calder Chair is the recognition by the external community. This recognition has opened doors earlier than would have occurred otherwise. One such example is the invitations to research prioritization workshops to which I've been invited to participate. 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.

- B. Khusid, J. S Allen, et al. Boiling, condensation and two-phase flows in microgravity. *National Academies Decadal Survey on Biological and Physical Sciences Research in Space 2023-2032*, 2021
- S. Shi, J. L. Plawsky, et al. Phase Change Processes for Thermal Management Systems and Science Investigations. In *Biological and Physical Sciences Research in Space 2023-2032*. National Academies, 2021

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 preparations for our ABET Accreditation visit this coming October 2023. The department self study report was submitted to ABET in early July. I am confident that our accreditation review will go smoothly.