THE UNIVERSITY OF TENNESSEE AT CHATTANOOGA

CENTER OF EXCELLENCE IN APPLIED COMPUTATIONAL SCIENCE AND ENGINEERING

Annual Report to the
Tennessee Higher Education Commission
Fiscal Year 2016-2017

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Submitted by
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University of Tennessee at Chattanooga

Center of Excellence in Applied Computational Science and Engineering

<u>MISSION STATEMENT</u>

To establish, expand and sustain a cohesive multidisciplinary effort in applied computational sciences leveraged across UTC to produce sustained growth in research funding, excellence in integrated education and research, growing numbers of PhD graduates in these applied areas, and to increase national and international stature and competitiveness in Tennessee.

<u>VISION STATEMENT</u>

UTC's cohesive multidisciplinary effort in applied computational sciences is recognized for its contributions to the community, the state of Tennessee, the region, and our nation for its solution of problems of importance to society, including the creation of useful inventions based on the applied science and engineering research. Participating UTC's under-graduate and graduate students graduate to become knowledge workers who contribute routinely through their specialized training to their community, state, region, and nation.

EXECUTIVE SUMMARY

UTC's Center of Excellence in Applied Computational Science and Engineering (CEACSE) has embarked on its second decade of invigorating scientific inquiry, bolstering the learning environment, broadening participation, and establishing sustainable research pathways that benefit our institution, faculty and students, and the State of Tennessee. With our previous report for FY2016, CEACSE marked its eleventh year growing UTC's first Center of Excellence into a critically important incubator for inquiry and experimentation across a diverse array of computational science and engineering endeavors. This report for FY2017 follows up our previous report (FY2016) with CEACSE's focused priority areas, highlights the maturation of its visionary leadership team, and notes greater impacts across a range of stakeholder groups. *CEACSE comprises the indispensible factor that enables UTC to recruit, retain, and engage outstanding professors and equally outstanding students through research experiences for undergraduates up to and including our PhD students.*

CEACSE research and advanced development activities enhance education at all academic levels at UTC including through the Ph.D. program in Computational Science. Graduate and undergraduate students alike participate in various research activities undertaken as a result of current and prior CEACSE funding. Companies in our community and region continue to have growing interest in the educational programs impacted by CEACSE initiatives in large measure because of the applied R&D supported by CEACSE. In the current year, SimCenter and the College of Engineering and Computer Science (CECS) are broadening efforts to partner with companies in the Chattanooga region and beyond. Because of increasing capabilities in high-performance computing and the growing importance of modeling, simulation, and advanced computing in research and education, the efforts and outcomes of our researchers and their students will continue to serve as research anchors attracting students from across the nation and internationally. These students represent a valuable contribution to the future workforce of knowledge workers for the community and the state of Tennessee.

The high-performance computing (HPC) capabilities associated with the new UTC heterogeneous GPU-enabled cluster (a high-end, 33-node, 64-bit Intel-architecture cluster with NVIDIA P100 GP-GPUs) were important differentiators leading to key programmatic accomplishments in FY2017 including:

- Securing extramural support for modeling and simulation of turbomachinery as a result of CEACSE investment –Webster's, Sreenivas', and Tanis' proposal to HPCMP PETTT[1] entitled "Heterogeneous HPC for High-order Stabilized Finite-elements on Moving and Deforming Domains" was funded with Engility Corporation at $421,997 over two years, commencing October 2017.
- Securing extramural support for a new joint project of an approximately $900,000 budget for UTC over three years with the University of Dayton Research Institute

[1] Department of Defense (DoD) HPCMP User Productivity Enhancement, Technology Transfer, and Training

(UDRI), Purdue University, the University of Tennessee Space Institute (UTSI), and the University of Tennessee at Knoxville (UTK) to model and simulate critically important multi-physics processes associate with hypersonic flight with the objective to design reusable hypersonic vehicle structures. This award is pending release of the FY2018 federal budget.

- A successful live demonstration by UTC researchers led by Dr. Sartipi of connected autonomous vehicles during the June *US Ignite Application Summit and Smart Cities Connect Conference* in Austin, TX, was using the UTC HPC capabilities developed by CEACSE (see https://youtu.be/-cHoB-FYam0).
- A second US Ignite Grant was awarded to Dr. Dalei Wu, as noted in his report: $299,884 over the period of January 2017-December 2019. Dr. Sartipi was the first US Ignite awardee at UTC some months earlier.
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Important technical advancements achieved in FY2017 include these highlights:

- The Reising/Sartipi/Loveless project for "Smarter Buildings Through Smarter Models" is now moving to experimental validation using the Building Efficiency Facility at Oak Ridge National Laboratory (ORNL).
- The Tenasi structured code project led by Dr. Arabshahi for hypersonic flow was tested and advanced to support realistic geometries up to higher Mach numbers than previously possible, while achieving good agreement with experiment.
- Refactoring of the FUNSAFE FORTRAN-based CFD application to C++with the additional capability of using GP-GPU offload (with successful testing and validation on the new cluster).
- As a contribution both to Urban Studies and Health, a prototype of a potential tool for urban planners was created by Heath et al that can be used to maintain/build good/safe road/street networks and urban facilities to support active transportation and physical activities among residents. Their models assessing the impact of increased exposure to dedicated transport/ recreation sidewalks/bike paths demonstrated a decrease in physical inactivity among adult residents in Chattanooga by a range of 25% to 50%, with a corresponding decrease in chronic diseases and their associated costs by as much as $1.2M over a project 4-year period, thus providing evidence for a return-on-investment for constructing such sidewalk/ pathways.

Additionally, the new cluster is instrumental in the work of faculty recruited during FY2017 and beyond, including High Performance Computing research conducted by the new SimCenter Director, Dr. Tony Skjellum. The cluster is a key local investment that enables leveraged access to remote facilities at much larger scales by supporting proofs-of-principle and key findings ahead of further scale-up and scale-out on leadership class machines available through NSF XSEDE, and through DOE (such as Oak Ridge National Laboratory), among others. It is therefore expected to be of great use during its several years of remaining useful life as an enabling scalable computing platform. And, it has current added benefits for teaching modeling, simulation, and high performance computing apart from its primary research functions.

In collaboration, CECS, SimCenter, and the Office of the Vice Chancellor for Research foster a rapidly expanding and enhancing culture of securing external funding as an outcome of seed research funding provided by CEACSE. We recognize the challenges for faculty to excel in attracting extramural funding while meeting all aspects of meritorious scholarship. We provide support through the Office of Research and Sponsored Programs (ORSP), through focus on opportunities that are designed to lead to larger funding awards, and through development of strategic partnerships. CEACSE is emerging as the nexus of research incubation, high performance computing and data science, as well a key provider of faculty resources that complement and supplement ORSP's offerings and add to those of faculty home departments.

This document constitutes the Annual Report for Fiscal Year 2017 of CEACSE activities and efforts. On behalf of the University of Tennessee at Chattanooga, the SimCenter , the College of Engineering and Computer Science, our community partners and stakeholders, as well as our CEACSE-funded scientists and students, we express our deep appreciation to THEC for this critically important support of the CEACSE.

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FACULTY & STAFF

The Center for Excellence in Applied Computational Science and Engineering benefits from institutional leadership who are deeply committed to enriching and expanding computational science as a research area and an enabler of innovative research across academic departments. The THEC Chair of Excellence is Dr. Tony Skjellum who joined the campus in August 2017. Please see the **Contact Information** section for details and biosketches for leadership personnel.

CEACSE FY2017 AWARDEES

The following faculty and staff were integral to the strategic direction of CEACSE during the 2016-17 competition cycle. As noted below, these individual served as a Lead PI and/or Co-Investigator on projects that advanced the CEACSE mission and vision. Biosketches have been added for all faculty in Appendix A.

Dr. Abi Arabshahi
Lead PI: *Computational Simulations of the Aerothermal Environment of Hypersonic Fight Vehicles*, *Numerical Simulation of Airflow in the Small Human Airways*
Co-Investigator: *Near Real-Time Detection of Anomalous Power Consumption in Smart Power Distribution Networks*, *Towards Simulation of Vertical Axis Wind Turbines in Offshore Settings*, *FUNSAFE Framework Development for Enhanced Multidisciplinary and Multiphysics Simulations*, *Numerical Simulations of Axial Compressor Flow Fields Employing Higher-Order Accuracy*

Dr. Arabshahi is a Research Professor in the Mechanical Engineering Department / SimCenter. He received a B.S. (1982) in Civil Engineering and an M.S. (1985) and a Ph.D. (1989) in Aerospace Engineering from the Mississippi State University. His research interest includes computational fluid dynamics, unsteady viscous flow applications, structured and unstructured grid technologies, autonomous underwater vehicles, internal and external aerodynamics and hydrodynamics and computational bio-fluid dynamics. He has authored papers on these areas in refereed journals, conferences and symposiums. He actively involves students into his research. Dr. Arabshahi's expertise in aerodynamic simulations has been instrumental for several projects in this award cycle. Please refer to Dr. Arabshahi's biosketch in Appendix A.

Dr. Trevor Elliott
Lead PI: *Investigation of Resources and Planning for Advanced Manufacturing Applications Center (AMAC) at UT Chattanooga*

Trevor S. Elliott is an Assistant Professor of Mechanical Engineering at the University of Tennessee at Chattanooga (UTC). He is an active member of the American Institute of Aeronautics and Astronautics (AIAA) Hybrid Rocket Technical Committee (HRTC) and is currently serving as Co-Technical Area Organizer (TAO) for the International AIAA Joint Propulsion Conference (JPC). At UTC he serves as Faculty Advisor for the UTC Racing Mocs Baja SAE competition teams, Hardware Counselor for the Chattanooga Student Chapter of IEEE, and Faculty Advisor for the Students for the Exploration and Development of Space (SEDS) competition teams. His research interests include Additive Manufacturing, Alternative Energy, Automotive Design, Combustion Stability, Compressible Flow, Data Analytics, Engineering Design, Fluid Mechanics, Propulsion, Smart Control, Spectral Theory, and Turbomachinery. He actively involves students with his research through design projects, funded research projects, and departmental honors projects. He has authored papers on the above areas in refereed journal and conference proceedings. He is also a reviewer for the International Journal of Energetic Materials and Chemical Propulsion (IJEMCP) and AIAA manuscripts. He holds Lifetime membership with the AIAA, the American Society of Mechanical Engineers (ASME), and the Association for Computing Machinery (ACM). Please see Dr. Elliot's biosketch in Appendix A.

Dr. Gregory Heath
Lead PI: *Intelligent Urban Planning*

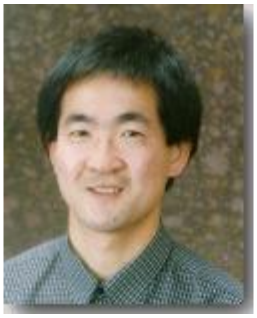
Gregory W. Heath is the Assistant Vice Chancellor for Research, Guerry Professor of Health and Human Performance, and also serves as Director of Research at the University of Tennessee College of Medicine, Chattanooga. Dr. Heath was formerly with the Division of Nutrition, Physical Activity, and Obesity at the U.S. Centers for Disease Control and Prevention (CDC), where he spent over 20 years initially starting as an Epidemic Intelligence Service (EIS) Officer. He has a background in physiology, nutrition, and epidemiology and holds both his masters and doctoral degrees from Loma Linda University School of Public Health in California. Dr. Heath has spent most of his professional career devoted to the understanding and promotion of physical activity and exercise for the enhancement of health as well as the prevention and management of chronic diseases. He is widely published in the preventive medicine and public health literature. Dr. Heath is a fellow in the American College of Sports Medicine (ACSM) and the American Heart Association's Council on Epidemiology. Please see Dr. Heath's biosketch in Appendix A.

Dr. Farah Kandah
Lead PI: *Quality of Service Assurance Using GENI, A Robust Network Design in Cognitive Radio Networks*
Co-Investigator: *Multiscale Serviceability Analysis and Assessment of Urban Infrastructure*

Dr. Farah Kandah is a UC Foundation Assistant Professor in the Department of Computer Science and Engineering at the University of Tennessee, Chattanooga, TN. He earned his Ph.D. from the Computer Science department at North Dakota State University, Fargo, ND. He received his M.Sc. from the Computer Science Department at the University of Jordan. He has been serving on the technical committee or organization committee of many internationally reputable conferences, such as CHINACOM, IEEE GLOBECOM, and IEEE WCNC. His research interests and experience span a wide range of topics in computer networks from stationary wireless/wired networks to mobile ad-hoc networks, including Security and Privacy as well as performance optimization in Wireless Networks, Software Defined Networks and Cloud Computing. He has multiple publications in multiple internationally reputable journals and conferences including; WILEY Security and Communication Networks (SCN) journal, ACM/Springer Mobile Networks & Applications (MONET) journal, IEEE Global Telecommunications Conference (IEEE GLOBECOM) and IEEE International Conference on Communications (IEEE ICC). Please see Dr. Kandah's biosketch in Appendix A.

Dr. Joseph Kizza
Lead PI: *Trust Propagation and Distrust in Web of Trust and Airborne Networks Authentication*
Co-Investigator: *Multiscale Serviceability Analysis and Assessment of Urban Infrastructure*

Dr. Joseph M. Kizza is a Professor and Head of the Department of Computer Science and Engineering at the University of Tennessee at Chattanooga (UTC). He is on editorial boards of half a dozen scholarly journals and Editor-in-Chief of the International Journal of Computing and ICT Research (IJCIR). He is an internationally known speaker on social computing and information security and assurance and has published extensively in journals and conference proceedings including more than ten books on computer ethics, network security and cyber ethics. Some of these books have been translated into several languages including Japanese and Chinese. He is a member of ACM. Please see Dr. Kizza's biosketch in Appendix A.



Dr. Yu Liang
Co-Investigator: *Multiscale Serviceability Analysis and Assessment of Urban Infrastructure*

Dr. Yu Liang is an Associate Professor in the Department of Computer Science and Engineering of University of Tennessee at Chattanooga as. His funded research projects cover the following areas: big-data and cloud computing, multiscale modeling and simulation, high-performance scientific and engineering computing, numerical linear algebra, sensor-oriented machine learning, computational mechanics (with focus on structural mechanics and biomechanics), and fault-tolerance techniques. His research work has appeared in various prestigious journals, book or book chapters, and refereed conference, workshop, and symposium proceedings. He owns one technical pattern that is registered at Univ. of Tennessee Research Foundation (UTRF). Dr. Liang is serving in the International Journal of Security Technology for Smart Device (IJSTSD), Journal of Mathematical Research and Applications (JMRA), and Current Advances in Mathematics (CAM) as an editorial board member. Please refer to Dr. Liang's biosketch in Appendix A.

Dr. Daniel Loveless
Lead PI: *Modeling Space and Defense Environmental Effects in Emerging Integrated Circuit Technologies*
Co-Investigator: *Smart Buildings through Smarter Models*

Dr. T. Daniel Loveless is a UC Foundation Assistant Professor of Electrical Engineering at the University of Tennessee at Chattanooga (UTC). He received the B.S. degree in electrical engineering from the Georgia Institute of Technology in 2004 and the M.S. and Ph.D. degrees in electrical engineering from Vanderbilt University in 2007 and 2009, respectively. Prior to joining UTC, he was a Research Assistant Professor at the Vanderbilt University Institute for Space and Defense Electronics where he was involved in the modeling and design of integrated circuits for the evaluation of radiation effects in advanced CMOS technologies. Dr. Loveless has authored over 80 journal articles and conference papers. His honors include three best conference paper awards, the IEEE Nuclear and Plasma Sciences Society (NPSS) Graduate Scholarship Award for recognition of contributions to the fields of nuclear and plasma sciences, and the Georgia Tech Alumni Association Scholarship. He is a Senior Member of the Institute of Electrical and Electronic Engineers (IEEE). His research interests include: embedded systems based on field-programmable gate arrays (FPGAs), microprocessors and microcontrollers, systems-on-chip, CubeSat design, radiation effects and reliability in electronic and photonic integrated circuits, high-performance and radiation-hardened digital, mixed-signal and analog integrated circuit design, sensors, and development of smart cities. Please see Dr. Loveless's biosketch in Appendix A.

Dr. James Newman
Lead PI: *FUNSAFE Framework Development for Enhanced Multidisciplinary and Multiphysics Simulations*
Co-Investigator: *Intelligent Urban Planning*

Dr. James Newman is a Professor in Mechanical Engineering. He has been active in the areas of multidisciplinary analysis, sensitivity analysis, and computational design optimization since 1994. Prior to this, Dr. Newman's focus area was in the simulation of complex-steady and unsteady moving boundary configurations using both unstructured grid and structured grid domain-decomposition techniques. Dr. Newman has developed software to perform computational fluid-structure, and fluid-thermal, interaction and analysis as well as pioneered new algorithms for evaluating multidisciplinary sensitivity derivatives and for uncertainty analysis. Additionally, he and fellow researchers have created a high-order finite-element based framework enabling multiphysics simulations encompassing fluid dynamics, structural dynamics, electromagnetics, and acoustics. Please see Dr. Newman's biosketch in Appendix A.

Dr. Donald Reising
Lead PI: *Smart Buildings through Smarter Models*

Dr. Donald R. Reising is an Assistant Professor of Electrical Engineering at the University of Tennessee at Chattanooga. He received his B.S. degree in Electrical Engineering from the University of Cincinnati in 2006. He received his M.S.E.E. (2009) and Ph.D. (2012) in Electrical Engineering from the Air Force Institute of Technology. His research interests include wireless device discrimination using RF-DNA fingerprints, digital communications, digital signal processing, and compressive sensing. He is a member of Eta Kappa Nu, Tau Beta Pi, and a senior member of IEEE. Please refer to Dr. Reising's biosketch in Appendix A.

Dr. Mina Sartipi
Lead PI: *Smart Urban Connectivity Powered by Mobility-on-Demand Public Transportation and Citywide Public Communications*, *Sensing Communications and Analysis in Smart Grid*
Co-Investigator: *Smart Buildings through Smarter Models* and *Intelligent Urban Planning*

Dr. Mina Sartipi is a UC Foundation Professor in the Department of Computer Science and Engineering. She is a Program Leader for Urban Science & Technology at University of Tennessee Chattanooga (UTC). She also leads the Smart Communications and Analysis Lab (SCAL). At SCAL, we leverage our expertise on data science (data analytics and data management) and wireless communications in smart city applications such as transportation, health, and energy. More specifically, SCAL focuses on research in Urban Science and Urban Analytics, Data Acquisition and Compressive Sensing, Data Integration, Data Interoperability, Big Data Analytics, Smart Health, Smart Grid, Intelligent Transportation, Information Processing for Wireless Sensor Networks, Cyber-Physical Systems (CPS), Modern Error Control Coding and Information Theory, and Signal Processing and Wavelet Transform. Please see Dr. Sartipi's biosketch in Appendix A.

Dr. Nur Sisworahardjo
Lead PI: *Near Real-Time Detection of Anomalous Power Consumption in Smart Power Distribution Networks*

Dr. N. Sisworahardjo is an Associate Professor of Electrical Engineering at the University of Tennessee at Chattanooga where he conducts research in the areas of power distribution state estimation, detection of anomalous power consumption in power distribution networks, generating unit asset valuation, load forecasting, distributed generation (fuel cells & microturbine) modeling, distributed generation penetration, and post-disturbance network reconfiguration. His general research interest including smart grid, distributed generation, renewable/alternative energy, power systems operation, optimization, simulation, and planning. Dr. Sisworahardjo has authored 25 journal articles, conferences papers, and book chapters. These papers not only deal with his research interests but also related to engineering education. Please see Dr. Sisworahardjo's biosketch in Appendix A.

Dr. Kidambi Sreenivas
Lead PI: *Towards Simulation of Vertical Axis Wind Turbines in Offshore Settings*
Co-Investigator: *Near Real-Time Detection of Anomalous Power Consumption in Smart Power Distribution Networks, FUNSAFE Framework Development for Enhanced Multidisciplinary and Multiphysics Simulations, Optimizing FUNSAFE for Leadership-class Machines, Computational Simulations of the Aerothermal Environment of Hypersonic Fight Vehicles, Modeling Space and Defense Environmental Effects in Emerging Integrated Circuit Technologies, Numerical Simulations of Axial Compressor Flow Fields Employing Higher-Order Accuracy*

Dr. Kidambi Sreenivas is an Associate Professor in Mechanical Engineering. He has been active in the area of unstructured, multi-physics flow solvers since 1996. Prior to this, his focus was in the area of structured flow solver development with applications to acoustics and stability of turbomachinery. Dr. Sreenivas pioneered the capability to enable rotating machinery simulations using unstructured meshes. Additionally, he has developed pre-conditioners that enable simulations of fluids with non-ideal equations of state. Dr. Sreenivas has applied these advanced capabilities to solve real-world problems involving complex geometry and complex physics. The range of applications include maneuvering submarines and surface ships, simulations of wind farms, multi-stage turbomachinery, improvement in aerodynamic efficiency of Class 8 trucks, particle deposition within the human respiratory system, contaminant dispersal through urban environments, and embedded propulsion systems. Dr. Sreenivas has worked closely with researchers from NASA, Navy, Department of Energy and various private companies and has transitioned the latest developments to provide them with advanced flow simulation capabilities. Please see Dr. Sreenivas' biosketch in Appendix A.

Dr. Craig Tanis
Lead PI: *Optimizing FUNSAFE for Leadership-class Machines*
Co-Investigator: *Smart Urban Connectivity Powered by Mobility-on-Demand Public Transportation and Citywide Public Communications*

Dr. Craig Tanis is an Assistant Professor in department of Computer Science and Engineering who researches the use of programming language techniques in high performance computing, helping application scientists develop correct codes without compromising computational efficiency. His expertise lies in high performance computing, programming languages, interactive multimedia. Please see Dr. Tanis' biosketch in Appendix A.

Dr. Robert Webster
Lead PI: *Numerical Simulations of Axial Compressor Flow Fields Employing Higher-Order Accuracy*, *Computational Simulation of a Blow-Down Tunnel for Turbine Testing at Purdue*
Co-Investigator: Towards Simulation of Vertical Axis Wind Turbines in Offshore Settings, FUNSAFE Framework Development for Enhanced Multidisciplinary and Multiphysics Simulations, Computational Simulations of the Aerothermal Environment of Hypersonic Fight Vehicles,

Dr. Robert S. Webster is an Associate Professor in the Mechanical Engineering Department at the University of Tennessee at Chattanooga (UTC). He has been involved in various areas of aerospace propulsion since the beginning of 1989. For three years, he gained experience as an engineer with NASA by serving as an engine system analyst for the Liquid Propulsion Systems Branch at the Marshall Space Flight Center. This provided an appreciation for understanding that most everything must function as part of a system. Since that time, he has been involved in various aspects of aerospace propulsion applications through the use of computational fluid dynamics. This computational experience consists of simulating flow fields of, for example, helicopter rotors, high-speed internal and external flows related to launch vehicles, turbomachinery flow fields, primarily for fan and compressor aero-dynamics of air-breathing engines, and both ideal-gas and equilibrium-chemistry nozzle flows. In short, his underlying interest is in the physics of aero-thermal flow fields. As the general area of aerospace propulsion is a combination of fluid mechanics, thermodynamics, and heat transfer, this field serves as a means for naturally satisfying his professional interests. He is a Member of the American Society of Mechanical Engineers (ASME), a Senior Member of the American Institute of Aeronautics and Astronautics (AIAA), newly elected Member of the AIAA Inlets, Nozzles, and Propulsion Systems Integration Technical Committee, and an Emeritus Member of the AIAA Gas Turbine Engines Technical Committee. Please see Dr. Webster's biosketch in Appendix A.

Dr. Dalei Wu
Lead PI: *Multiscale Serviceability Analysis and Assessment of Urban Infrastructure*

Dr. Dalei Wu is an Assistant Professor with the Department of Computer Science and Engineering at the University of Tennessee at Chattanooga (UTC). Before joining UTC, he worked as a Postdoctoral Researcher with the Mechatronics Research Laboratory at Massachusetts Institute of Technology (MIT). His areas of expertise include intelligent systems, data analytics, sensor networks, and mobile computing. His is particularly interested in using methods of modeling, optimization, and machine learning to solve real-world problems. He has published research papers in the following journals: ACM Transactions on Modeling and Computer Simulation, IEEE Transactions on Industrial Informatics, IEEE Transactions on Automatic Control, IEEE Transactions on Circuits and Systems for Video Technology, IEEE Transactions on Wireless Communications, IEEE Journal on Selected Areas in Communications (JSAC), IEEE Transactions on Multimedia, and IEEE Transactions on Communications. He is the PI of NSF US Ignite project (CNS #1647175) on Focus Area 1: Fiber Network for Mapping, Monitoring and Managing Underground Urban Infrastructure (01/2017 – 12/2019). He is editor-in-chief of the International Journal of Information Security and Privacy, and associate editor of Wiley Security and Communication Networks Journal. Please see Dr. Wu's biosketch in Appendix A.

Dr. Li Yang
Co-Investigator: *Multiscale Serviceability Analysis and Assessment of Urban Infrastructure*

Dr. Li Yang is a Guerry Professor and Assistant Dean in the College of Engineering and Computer Science. She is the Director of UTC Information Security (InfoSec) Center, a National Center of Academic Excellence in Information Assurance/Cyber Defense (CAE-IA/CD). Her research interests include network and information security, big data analytics, massive data mining, bioinformatics, and engineering techniques for complex software system design. She actively involves students into her research. She authored papers on these areas in refereed journal, conferences and symposiums. She is editor-in-chief of the International Journal of Information Security and Privacy. She has secured over four million external funding from National Science Foundation (NSF), National Institute of Health (NIH), Department of Defense (DoD), and Oak Ridge National Laboratory (ORNL). Please refer to Dr. Yang's biosketch in Appendix A.

AWARDEES WITH SUPPLEMENTAL FUNDING CONTINUING FROM PREVIOUS FISCAL YEARS

Dr. Neslihan (Nesli) Alp
Co-Investigator: *Energy Performance of Residential Building Using Simple-Normalization Based Two-Stage Data Envelopment Analysis*

Dr. Neslihan Alp is a Professor and Department Head of the Engineering Management & Technology Department and Associate Dean of the College of Engineering and Computer Science (CECS). She holds the Chattanooga Manufacturers Association (CMA) Chair position in CECS. Dr. Alp earned a Ph.D. in Engineering Management from the University of Missouri-Rolla (Missouri University of Science &; Technology) (1996), a master's degree in Industrial Engineering, and a bachelor's degree in Engineering Management from Istanbul Technical University, Turkey. Her teaching and research interests and expertise are in the areas of project management, quality control, facilities management, optimization, lean systems, manufacturing processes, and distance education. She is a member of the American Society for Engineering Management (ASEM), American Society of Engineering Education (ASEE), Industrial and Systems Engineering (ISE), American Society of Quality (ASQ), Project Management Institute (PMI), and Society of Women Engineers (SWE). She currently serves as the SWE Student Chapter's Faculty Advisor. She strongly advocates for female and other minority students in the STEM field. Please see Dr. Alp's biosketch in Appendix A.

Dr. Endong Wang
Lead PI: *Energy Performance of Residential Building Using Simple-Normalization Based Two-Stage Data Envelopment Analysis*

Dr. Endong Wang is an Assistant Professor in the Engineering Management & Technology Department at UTC. He obtained his Ph.D. in Construction Engineering from the University of Nebraska, Lincoln. Before joining UTC, he worked as a Postdoctoral Researcher in Mechanical Engineering. His research interests include sustainable construction, building energy performance evaluation, thermal detection, decision making, and environmental assessment. He has teaching experience at both undergraduate and graduate levels in both U.S. and China. He has been on the review board of multiple journals and the technical committee of several international conferences. Please refer to Dr. Wang's biosketch in Appendix A.

STUDENTS

Project Title: Investigation of Resources and Planning for Advanced Manufacturing Applications Center (AMAC) at UT Chattanooga
Lead PI: Trevor Elliott

Students Impacted	*Please list students including name, brief description of how they were impacted, what degree sought or when graduated, and any other relevant details.* Chase Dobbins – Mechanical Engineering Student – Graduated Fall of 2016. Expanded on his knowledge of dealing with vendors for technical and quote materials. Expanded on 2D/3D modeling experience by completing the last iteration of manufacturing space layout. Learned the detailing of a comprehensive business plan with competitive analysis and asset costing. Currently using experience to search for a position in advanced manufacturing or aerospace. All of the current and future ENME 4500 (or equivalent design course) While researching certifications of interest to industrial partners learned of free access to Lean Six Sigma White Belt certification test. Implemented course materials and certification this into the 4500 course for all ME students to graduate with this certification.

Project Title: Healthy and Intelligent Transportation Planning: Estimating Return on Investment Associated with Improved Infrastructure for Bicycling and Walking and Decreased Physical Inactivity in Chattanooga/Hamilton County
Lead PI: Gregory W. Heath

Students Impacted	*Please list students including name, brief description of how they were impacted, what degree sought or when graduated, and any other relevant details.* Graduate Students in Computer Science and Engineering were exposed to the modeling of environmental (air quality) data

Project Title: Modeling Space and Defense Environmental Effects in Emerging Integrated Circuit Technologies
Lead PI: T. Daniel Loveless

Students Impacted	*Please list students including name, brief description of how they were impacted, what degree sought or when graduated, and any other relevant details.* Undergraduate Students: Ellis Richards, Ryan Boggs Graduate Students: Amee Patel, Matthew Joplin Amee Patel: Mrs. Patel was partially funded by the award and facilitated student training on relevant software for the design of the MSM instrument. Mrs. Patel graduated with her M.S. degree in Electrical Engineering and took a position as an embedded systems designer for La-Z-Boy furniture. Ellis Richards: Mr. Richards was partially funded by the award as an undergraduate student. He utilized the Lumerical software suite for simulation and analysis of photonic structures. After graduation Ellis received a stipend position at Vanderbilt University where is studying radiation effects and reliability. Matthew Joplin: Mr. Joplin was partially funded by the award and was responsible for the design and layout of the MSM instrument. Matt is a current graduate student. Ryan Boggs: Mr. Boggs was partially funded by the award as an undergraduate student. He has continued with efforts started by Ellis, and is now a graduate student at UTC. Ryan is also supporting the modeling effort. Students at the undergraduate and graduate levels were involved in all phases. Further, the work was conducted in collaboration with academic and industrial leaders in the area of high reliability, low power microelectronics.

Project Title: Smart Buildings Through Smarter Models
Lead PI: Donald Reising

Students Impacted	*Please list students including name, brief description of how they were impacted, what degree sought or when graduated, and any other relevant details.* Graduate Students: Mohammed Fadul, Amee Patel, Jin Cho Mohammed Fadul: Mr. Fadul is seeking a Master's of Science in Electrical Engineering. Mr. Fadul carried out all of the work related to the construction of the building energy model within the modeling and simulation tool EnergyPlus™. This work pushed Mr. Fadul to work in an area in which he had little to no experience in, and he excelled. This work was invaluable to further developing his critical thinking and problem solving skills as well as transitioning from undergraduate to a graduate level of work. Jin Cho: Jin is finishing his Master's degree in Computer Science this fall. This was a great opportunity for him to expand his data science expertise with a real-world application. Amee Patel: Mrs. Patel was partially funded with the award and was responsible for the development of the networked sensor array. Her efforts with sensor calibration and network design led to completion of her degree of Masters of Science in Electrical Engineering.

Project Title: Smart Urban Connectivity Powered by Mobility-on-Demand Public Transportation and Citywide Public Communications
Lead PI: Mina Sartipi

Students Impacted	*Please list students including name, brief description of how they were impacted, what degree sought or when graduated, and any other relevant details.* Undergraduate Students: Robert Barber, Caleb Campbell Graduate Students: Hector Suarez, Austin Harris Robert Barber: Robert learned more about routing algorithms as well as Python packages. After being involved in this exciting research project, Robert decided to stay for graduate school. Caleb Campbell: Caleb was able to expand her knowledge on graph theory and data structures. Hector Suarez and Austin Harris were able to work as a team on several aspects of this project. They also learned how to manage the project as at times the PI asked them to set the goals, justify them, and work with the undergraduate students on the team.

Project Title: Near Real-time Detection of Anomalous Power Consumption in Smart Power Distribution Networks,
Lead PI: Nur Sisworahardjo

Students Impacted	*Please list students including name, brief description of how they were impacted, what degree sought or when graduated, and any other relevant details.* Graduate Student: Akram Saad One graduate student participated in this project. Through the project, the student gained first-hand experience in research and scholarship activities. The student had the opportunity to write a technical report, which leads to paper(s) publication in a conference/journal..

Project Title: Towards simulation of vertical axis wind turbines in offshore settings,
Lead PI: Kidambi Sreeenivas

Students Impacted	*Please list students including name, brief description of how they were impacted, what degree sought or when graduated, and any other relevant details.* Graduate Student: David Collao David Collao: David was responsible for creating the geometry and generating the meshes for this project. He became comfortable with using the CAD tools within Pointwise to create geometry as a result of this project. He has since graduated with a PhD in Computational Engineering (2017) and is currently employed by a local company that creates software for 3D modeling for dentures and other dental implants..

Project Title: Optimizing FUNSAFE for Leadership-Class Machines,
Lead PI: Craig Tanis

Students Impacted	*Please list students including name, brief description of how they were impacted, what degree sought or when graduated, and any other relevant details.* Undergraduate Student: Dominique Pennington Dominique Pennington, graduated May 2017, was quite helpful in studying the differences between Xeon Phi and NVIDIA GPU hardware. He was sent to a supercomputing symposium at Oklahoma State in support of this work. This work manifested itself distinctly in Dr. Tanis' Spring 2017 graduate course offering on Parallel Algorithms, particularly with respect to GPU programming..

Project Title: Multiscale Serviceability Analysis and Assessment of Urban Infrastructure
Lead PI: Dalei Wu

Students Impacted	*Please list students including name, brief description of how they were impacted, what degree sought or when graduated, and any other relevant details.* **Undergraduate students pursuing bachelor degree in Computer Science:** Robert Slaughter, Dakila Ledesma, Christopher Davis, Alaykumar Patel, Suhail Arora, Austin Obyrne, Peter Zeglen, Derek Snyder, Morgan Sanborn, Izabella Arredondo. **Graduate students pursuing Ph.D degree in Computer Science:** Maxwell Omwenga, Mehran Ghafari. **Graduate students pursuing master degree in Computer Science:** Sharmila Chackrawathy, Stuart Eudaly, Nada Alharbi, Maha Almaimani, Rabhu Bajracharya. Nada (female) published one conference paper as the first author. Robert Slaughter, Dakila Ledesma, and Christopher Davis submitted one conference paper as co-authors.

PROGRAM OVERVIEW & ACCOMPLISHMENTS

INTRODUCTION

The value proposition for multidisciplinary and inter-disciplinary research, education, and training in the rapidly advancing field of Computational Science and Engineering[2] (CSE) has grown stronger since the start of CEACSE in 2005. Today, modeling, simulation and high-performance computing are considered the third pillar of research, development and scientific inquiry (in addition to theory and experiment) in a broad spectrum of scientific and technical areas. The THEC investment in CEACSE continues to be critically important for UTC to strengthen ongoing interdisciplinary CSE efforts and to continue to improve competitiveness with respect to extramural funding. The primary objectives of CEACSE are as follows:

- Expand CSE capabilities at UTC;
- Support startup of new research and educational work that broadens and expands the CEACSE base of research expertise; and
- Realize appropriate return on investment by attracting new extramural funding.

Fiscal year 2017 has been a year of growth and enhancement for CEACSE. After several retirements and resignations of staff in the SimCenter, the appointment of new leadership has revitalized the environment for CEACSE at UTC. Dr. Reinhold Mann, who was Interim director of the SimCenter for two years, stepped down at the end of FY2017. Dr. Tony Skjellum joined from Auburn University as the new SimCenter, Professor of Computer Science, and Chair of Excellence soon thereafter. Dr. Skjellum's experience in creating successful multidisciplinary research centers, as well as his strong grounding in High Performance Computing and Simulation bring new leadership to SimCenter. He joins the existing group of established leaders highlighted in last year's report – Dr. Joanne Romagni, Vice Chancellor for Research, and Dr. Daniel Pack, Dean of the College of Engineering and Computer Science (CECS). In addition, Dr. Mann remains engaged as a consultant to Dr. Romagni and supports her office and SimCenter in their respective engagements with state, local, and federal opportunities nurtured and advanced during his two-year term as Interim Director. Dr. Skjellum will lead the CEACSE efforts moving forward, and plans to grow and support work consonant with the original proposal to THEC for CEACSE. Continued emphasis on modeling and simulation in CSE, high performance computing, and data science will ground the strategy of advancing and diversifying the participation of UTC faculty and students in CEACSE projects in FY2018 and beyond..

The FY2017 portfolio of CEACSE projects accomplished a number of foundational advancements in detailed R&D for computational solvers, for smart cities and urban studies R&D, for work in electric power, and also expanded CSE capabilities in important

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[2] "Future Directions in CSE Education and Research," report from workshop sponsored by SIAM and the European Exascale Software Initiative (EESI-2), held August 4-6, 2014; Breckenridge, CO – Draft, dated March 11, 2015 available at http://www.eu-maths-in.eu/download/General-International-Studies-Prospective/2015-CSE-report-draft.pdf.

new application areas such as modeling and simulation in other ways keyed to the availability of our new computing infrastructure.. Importantly, we were able to fund appropriate research projects in all five of the identified research foci (highlighted below), although Aerospace/Defense and Smart Cities remain the largest categories by proposals funded. These areas also have been well represented in new external research awards received by CEACSE-funded professors.

With the rapid march of technology in the era of GP-GPU-enabled computing, it was essential to modernize the locally available high performance computing cluster at UTC. To that end, an approximately $350,000 investment was made in FY2017, including approximately $250,000 of CEACSE funds (with and additional $100,000 from the UC Foundation), in support of a new cluster comprised of Dell-branded, multi-core Intel-architecture servers, each with an NVIDIA GP-GPU Pascal P100, and all connected via an InfiniBand EDR (100Gbit/s) low-latency interconnect. This 33-node cluster provides a revolutionary level of local infrastructure, and matches well with the sorts of clusters our peers and aspirational institutions use routinely. The availability of this system has enabled significant porting of valuable internal codes (*e.g.,* FUNSAFE) to use GP-GPU offload and thereby be able to solve larger and more complex problems. In particular, this system, together with baseline funding for code porting, has enabled our professors and students to solve bigger and harder problem locally while preparing them for access to leadership class machines outside of UTC, such as the forthcoming ORNL Summit system. Overall the combined investment in computing infrastructure and in the core R&D algorithms and code representations with CEACSE funds is designed at the key aim of enabling our scientists to run flow field simulations that will scale out successfully with performance with great performance-portability, and thus be able to target leadership class machines when to solve extremely demanding flow problems, such as hypersonic flows.

Important new collaborative alliances have been made in FY2017, perhaps none more relevant in the computational fluid dynamics area than the cooperation of UTSI, UTDI, UTK, and UTC researchers. As mentioned elsewhere in this report, an approximately $900,000 contract is pending for UTC as part of an overall $10M program to advance hypersonic flow R&D. This consortium of universities and research foundations joins UTC into a new level of massive collaboration with huge potential for solving key programs as part of its statement of work, while also opening the possibility of on-going support for the hypersonic R&D at UTC based on our unique and distinctive know-how, science, and engineering.

CEACSE STRATEGY AND ORGANIZATION

The scientific, technical and programmatic objectives of CEACSE are aligned with the strategic directions of the research and educational programs at UTC. Figure 1 (below) illustrates the central role CEACSE plays in capability and program development potentially impacting all Colleges at UTC. These strategies intersect with problems of global, national and regional importance in five primary focus areas:

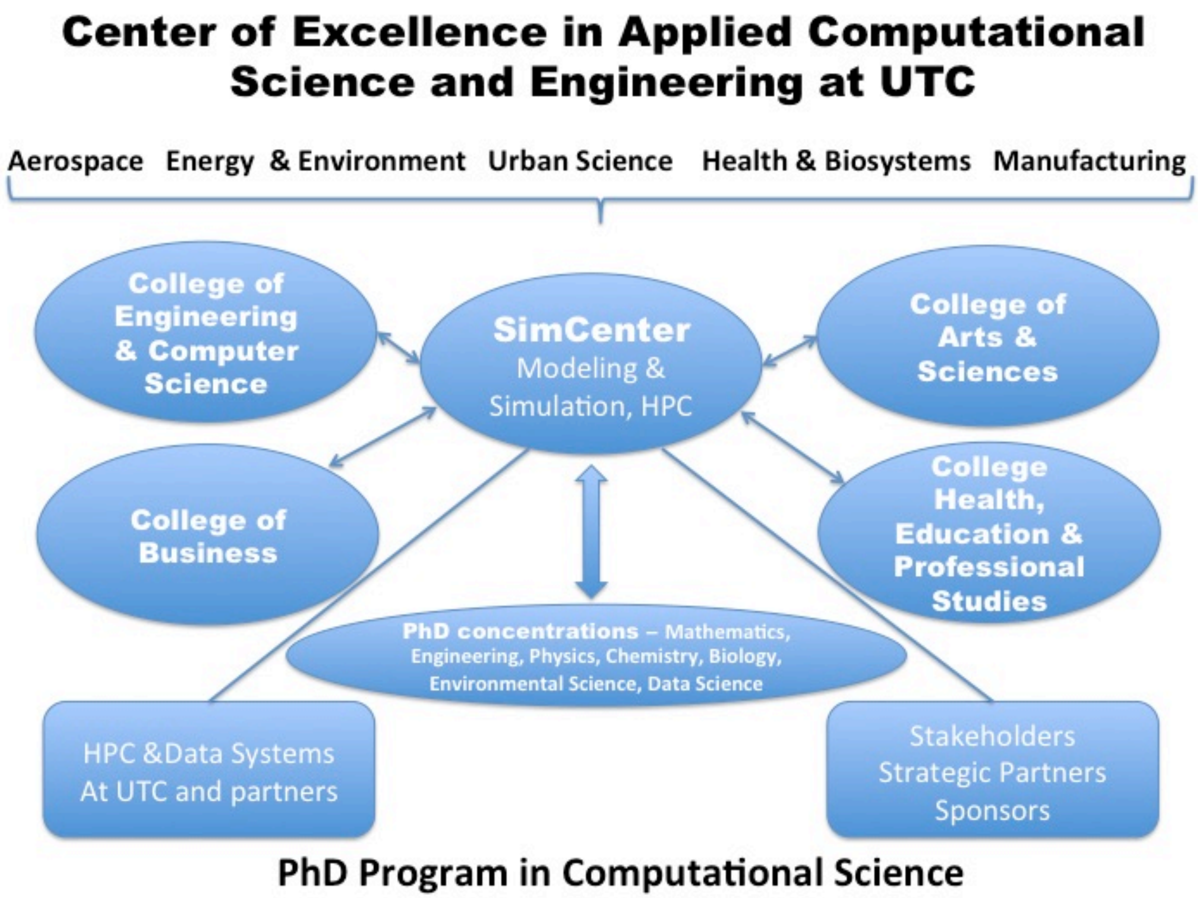
- Aerospace and Defense
- Energy & Environment
- Health & Biological Systems
- Manufacturing
- Urban Science and Technology

These application focus areas were selected based on three important criteria:

- The presence of significant scientific and technical challenges for which there was interest, expertise, and the potential to excel at UTC;
- Clear alignment with educational and workforce development missions of UTC;
- Opportunities to establish extramural R&D funding that can be realized by UTC researchers in strategic partnerships with collaborators at other institutions.

CEACSE proposals that fit one (or more) of these five focus areas are reviewed for technical merit by a panel of outside experts, then undergo a review for strategic alignment which includes scrutiny of a specific plan to develop extramural funding. While these five focus areas span a wide area of science & technology, all excellent ideas that appear outside of these five stated areas are considered so long as they have substantial CSE content.

F*igure 1: SimCenter serves as UTC's intellectual hub and incubator in modeling, simulation and HPC in collaboration with departments across campus. Drivers for the activities include the five focus areas described in this plan. In addition to Computer Science and Engineering, the PhD program will feature concentrations in Mathematics and other Sciences. Notably, progress toward expanding into Mathematics was achieved in the past year, and there is strong SimCenter participation by math faculty as of Fall 2017. The THEC Center of Excellence supports cross-disciplinary innovative efforts that are critically important to continued program development including high-quality faculty recruitment and national competitiveness for follow-on funding.*



Overview of FY2017 Projects

In FY2017, CEACSE awarded new seed funding to support the research activities of sixteen faculty members for twelve new projects from various disciplines across computational science and engineering. CEACSE continued its efforts to broaden the scope of research through increased participation of additional faculty, graduate students, and undergraduate students.

The funded projects key to the five priority areas: Aerospace and Defense (five projects), Energy & Environment (two projects), Urban Science (three projects), Health & Biosystems (one project), and Manufacturing (one project). Additionally, certain projects have elements that cross-cut multiple areas, such as Urban Science plus Energy & Environment.

Lead PI	Dr. Abdollah (Abi) Arabshahi
Co-PI(s)	Dr. Robert S. Webster
Other Personnel	None
Project Title	Computational Simulations of the Aerothermal Environment of Hypersonic Flight Vehicles
Award Start – End Date	July 1, 2016 – June 30, 2017
Summary	Continued advances in physics-based simulation technologies in general, and in Computational Fluid Dynamic (CFD) in particular, are essential and required to support almost every aspect of the Hypersonic project. These capabilities will be used to generate accurate numerical predictions to provide and enhance our understanding of the complex flow phenomena that occur at the hypersonic regime (such as aerothermodynamics, aerodynamic, chemical reactions, and high heat transfer) around any flight vehicle. Current effort at the UTC/SimCenter is to develop and validate a physics-based numerical capability for simulating flow around hypersonic aerospace vehicles and components of vehicles, so that performance can be more accurately evaluated and better understood.

Lead PI	Trevor S. Elliott
Co-PI(s)	(Originally Jan Evans)
Other Personnel	Chase Dobbins – Undergraduate student
Project Title	Investigation of Resources and Planning for Advanced Manufacturing Applications Center (AMAC) at UT Chattanooga
Award Start – End Date	August 8, 2016 – June 30, 2017
Summary	This work was centered on the development of a resource plan, personnel and infrastructural, related to creating a center for advanced manufacturing. To that end, faculty within the SimCenter, the college of engineering, and other colleges at UTC were linked to topic areas relevant to manufacturing. More specifically they were linked to areas found to be of interest to local manufactures and constituent base of UTC. While the manufacturer needs were assessed the center infrastructural requirements were analyzed. A major finding was that industries are not currently utilizing advanced techniques/technologies in their processes. These industries voiced a desire to test these new techniques and technologies within their current production and a need for integration with conventional processes. The subsequent research on integration yielded results about companies reacting to exactly this need, such as GF+ with a pallet system for moving products from conventional processes to advanced or additive processes in a bulk and automated fashion. This company indicated their process was in need of modeling and simulation similar to what the SimCenter could provide. In addition to the modeling and simulation needs this finding pointed out the possible need for a technology transfer component within the center. The facility layout produced within this work was a crucial element in space conversations and the space for the center has been secured. While creating the facility layout, equipment was assessed for its merits using a customized weighting scheme and desired equipment was selected for consideration. During the evaluation of potential equipment current faculty interests were considered which leads to a desired outcome of matched faculty interests to center subtopics and possible funding opportunities. The community impacts thus far have been in the area of awareness and soliciting of interested parties in the Chattanooga area. Entrepreneurial players such as CoLab, Branch Technologies,

	Collider Technologies, Feetz, and the Enterprise Center have been brought into the planning meetings for center realization. Industrial entities such as Komatsu, Tuftco, TN Rand, and Roper Company have been consulted to ascertain their needs and provide awareness about the center. Resources for certifications were located and resulted in an indirect student impact. These resources have now been implemented in a senior level course. The students in this course, all mechanical engineering students, will have the tools, training, and free access to certification for entry level lean six sigma certification.

Lead PI	Dr. Gregory W. Heath
Co-PI(s)	Dr. Mina Sartipi Dr. James Newman
Other Personnel	Mr. Andrew Mindermann – GIS Technician Dr. Guijing Wang – Health economist – CDC Mr. Eric Asboe – Transportation Planner- City of Chattanooga
Project Title	Healthy and Intelligent Transportation Planning: Estimating Return on Investment Associated with Improved Infrastructure for Bicycling and Walking and Decreased Physical Inactivity in Chattanooga/Hamilton County
Award Start – End Date	July 1, 2016 – June 30, 2017
Summary	Based on data related to environment, transportation, and health, we proposed to provide a customized 'environmental infrastructure and health return-on-investment calculator' to be used by planners and personal users to guide in planning for pedestrian/bicycle path cost outlays for the former and healthy active wayfinding by the latter. Transport and recreation path/sidewalk costs were assessed in partnership with the city of Chattanooga's Department of Transportation for both recent and projected transport and recreation construction costs, land costs, projected construction time, and populations reached. Physical inactivity behavior associated impact on heart disease, stroke, type 2 diabetes, colon cancer, and breast cancer prevention outcomes were calculated using: 1) the relative risk (RR) for each of the chronic diseases in association with estimates of physical inactivity; 2) accessing through the Behavioral Risk Factor Surveillance System, the current prevalence of physical inactivity among the adult population 18 years and older residing in Chattanooga/Hamilton County and specifically Census Tracts 16, 18, 19, and 20; 3) using the results from steps 1 and 2 to calculate a Chattanooga/Hamilton County-specific and Census-specific Population Attributable Fraction (PAF) for each of the physical inactivity and chronic disease outcomes; and

	4) Adjust the PAF's for each of the outcomes in accordance with the effect size expected from the sidewalks and paths on behavioral changes in terms of increased levels of physical activity among the adult population; and 5) adjusted cost of chronic disease's affected by changes in physical activity due to sidewalk/path changes. In addition, we created an application that provides a personalized planning for active transportation in response to vehicular traffic patterns and air quality so as to alert bike and pedestrian active transporters about the potential hazards and/or conditions of travel routes. Hence, in terms of urban planning, the data generated by our applications resulted in a potential tool that urban planners can use to maintain/build good/safe road/street networks and urban facilities to support active transportation and physical activities among residents. Our models assessing the impact of increased exposure to dedicated transport/recreation sidewalks/bike paths demonstrated a decrease in physical inactivity among adult residents in Chattanooga Census Tracts 16, 18, 19, 20 by a range of 25% to 50%, with a corresponding decrease in chronic diseases and their associated costs by as much as $1.2M over a project 4-year period, thus providing evidence for a return-on-investment for constructing such sidewalk/pathways.

Lead PI	Dr. T. Daniel Loveless
Co-PI(s)	None
Other Personnel	Amee Patel, Matthew Joplin - Graduate Students Ellis Richards, Ryan Boggs - Undergraduate Students
Project Title	Modeling Space and Defense Environmental Effects in Emerging Integrated Circuit Technologies
Award Start – End Date	July 1, 2016 – June 30, 2017
Summary	Typical electronics reliability modeling tools reside in a proprietary industry setting, employ techniques for a specific need, and are inappropriate for emerging integrated circuit technologies. Further, current methods involve extrapolation of short-term degradation profiles for predicting long-term behavior and lead to inaccurate and over constrained reliability predictions, and significantly limit the use of emerging integrated technologies in large distributed systems. This effort involved development of a stochastic based modeling technique for capturing intrinsic parameter fluctuations that account for time-dependent workload conditions influencing electronics reliability. Further, a novel method for measuring the stochastic behavior of atomic-level defects within electronics

	devices was developed. The hardware was provided to Sandia National Laboratories for measurement of time-dependent reliability in advanced and emerging semiconductor technologies. Future work will involve the collection of data for further improvement of the stochastic models, and the integration of the models into industry-standard simulation tools. This work offers a fundamentally new approach to evaluating system-level reliability vulnerabilities, enabling new approaches for mitigation, and has the potential for transforming the way industry assesses electronic device, component, and system reliability.

Lead PI	Dr. James C. Newman III
Co-PI(s)	Dr. Kidambi Sreenivas Dr. Robert Webster Dr. Abdollah Arabshahi
Other Personnel	None
Project Title	FUNSAFE Framework Development for Enhanced Multidisciplinary and Multiphysics Simulations
Date Submitted	March 7, 2016
Award Start – End Date	July 1, 2016 – June 30, 2017
Summary	The proposed research re-factored a version of the FUNSAFE framework to facilitate, enhance, and extend simulation capabilities. In the Review Summary for this award, reviewers commented that the research "does not strike me as overly creative or transformative", "This seems more like a support effort that should be funded under the other proposals rather than stand on its own", and "A clear path to future funding for a follow-on project is needed". Unfortunately, the reviewers did not recognize that funding opportunities may be pursued proactively through the development of creative and/or transformative research as well as arise based on unique capabilities/expertise possessed by the faculty. The latter falls under the category of reactionary opportunities, and particularly within the DoD, the vast majority of funding is obtained in this manner. The current award, and research conducted, not only enhanced capability, but will make UTC researchers' proposals more cost competitive. Furthermore, as discussed in a subsequent section, the current THEC award has already successfully attracted extramural funding. Moreover, with

	regards to being transformative, NASA within the Transformational Tools and Technologies Program, and in partnership with the United States Air Force, have recently embarked on a re-factoring effort for their simulation software that is similar to this project.

Lead PI	Dr. Donald R. Reising
Co-PI(s)	Dr. Mina Sartipi Dr. T. Daniel Loveless
Other Personnel	Mohammed Fadul, Amee Patel, Jin Cho - Graduate Students
Project Title	Smart Buildings Through Smarter Models
Date Submitted	
Award Start – End Date	July 1, 2016 – June 30, 2017
Summary	The effort assessed current building energy models and investigated methods by which to improve them using integrated sensor data. The goal was to improve upon the existing model to facilitate real-time, high-fidelity energy usage and efficiency analysis. The existing modeling software, used in this work, requires extensive knowledge of the building's construction (e.g., materials, dimensions), occupancy, and systems (e.g., HVAC, lighting). The program then returns a projected energy usage and efficiency based upon this model; thus, the accuracy of these projections rely heavily upon the accuracy of the model. However, the sensor data facilitates direct energy usage and efficiency based upon measured values without any knowledge of the building's construction, occupancy, and systems. This project advanced the SimCenter's work within the area of Urban Systems in which energy efficiency is a key focus. This work serves as a key preliminary step in the development of a process by which to facilitate real-time, high-fidelity energy usage and efficiency analysis with the goal of improving energy usage across the community.

Lead PI	Dr. Mina Sartipi
Co-PI(s)	Dr. Craig Tanis
Other Personnel	Hector Suarez, Austin Harris - Graduate Students Robert Barber, Caleb Campbell - Undergraduate Students
Project Title	Smart Urban Connectivity Powered by Mobility-on-Demand Public Transportation and Citywide Public Communications
Award Start – End Date	July 1, 2016 – June 30, 2017
Summary	In order to confront unprecedented challenges due to the rapid urbanization, we started a fundamental research on smart urban connectivity. We investigated the methodologies, feasibilities, and potentials of two essential connectivity paradigms for urban futures, i.e., cooperative mobility and citywide wireless communications. We developed a real-time graph for the streets of the city of Chattanooga that can be updated by crowdsourcing, designed personalized routing algorithms that consider features such as health, air quality, and elevation, and investigated a small testbed for advanced wireless communications. The proposed research involved computationally intensive data analytics, graph analytics, simulation and modeling, optimization, operations research, and urban planning. This project advanced the SimCenter's work within the area of Urban Systems in which transportation and wireless communications are key focuses.

Lead PI	Dr. Nur Sisworahardjo
Co-PI(s)	Dr. Abi Arabshahi Dr. Kidambi Sreenivas
Other Personnel	Akram Saad - Graduate student
Project Title	Near Real-time Detection of Anomalous Power Consumption in Smart Power Distribution Networks
Award Start – End Date	July 1, 2016 – June 30, 2017
Summary	Through this project, our team members (PI and co-PIs) gained tremendous experience in big data and data analytics and understand the possible utilization that not only limited to power industries but also in other disciplines. Strategic relationship with local industry was strengthened with extensive collaboration with EPB and provide us opportunity to further this collaboration in scholarship activities. From this grant one graduate student received full support for one year to persue his master degree. Through the project, student gained first-hand experience in research and scholarship activities. Student had opportunity to

	write technical report which leads to paper(s) publication in conference/journal. One paper was submitted and accepted for 2017 International Conference on High Voltage and Power System. Another paper is in preparation for possible publication in conference/journal. This research project also enable researchers at UTC to gain knowledge and experience in anomaly detection in distribution network and gain valuable lessons that can be disseminated to other public power utilities in the region and beyond.

Lead PI	Dr. Kidambi Sreenivas
Co-PI(s)	Dr. Abi Arabshahi Dr. Robert Webster
Other Personnel	None
Project Title	Towards simulation of vertical axis wind turbines in offshore settings
Award Start – End Date	July 1, 2016 – June 30, 2017
Summary	The objectives of this project were to take first steps towards the numerical simulation of the flow field surrounding vertical axis wind turbines (VAWT) in offshore settings. This work was carried out in collaboration with Sandia National Laboratory, with Dr. Todd Griffith as the POC. The idea behind the project was to carry out initial validation using data from a VAWT that Sandia had tested in the 70s and 80s. These experiments were carried out onshore and once this validation was completed, a future project (potentially funded through Sandia National Lab/DOE) would have involved transitioning the VAWT to an offshore setting. Almost all commercial wind turbines are three-bladed and of the horizontal axis variety. Consequently, there isn't a large body of research supporting VAWTs. This became abundantly clear as we looked for detailed geometry for the Sandia VAWT. The first roadblock we ran into was that proprietary airfoil sections were used in the Sandia VAWT. After significant back and forth between the PIs and Dr. Griffith, we were able to obtain the geometry of these airfoil sections. The second roadblock was that these wind turbines were built and tested in the era of "pencil and paper," i.e., there were no solid models (CAD) available that defined this geometry. Based on various reports we found (some were provided by Dr. Griffith), we reconstructed the geometry as best as we could. Even with this effort, these were significant doubts about the geometry definition and there was no way to verify the same as the test article does not exist anymore. Simulations were carried out based on the geometry

	we had created, but the results were not satisfactory. Consequently, attempts to get some of these results published were unsuccessful. Given that the simulations of the Sandia VAWT provided less than satisfactory results, we began the search for relatively recent experimental data, which had the added advantage of having well defined geometry. This search clearly showed us the paucity of experimental data for VAWTs. The only experimental dataset that could be found was completely fortuitous as the PI happened to be at a talk at the AIAA Aviation Conference in Denver (June 2017) where they discussed some of the results. The results were focused on details of the flow field as opposed to the power produced by the VAWT. Additional searches after the conference turned up one more dataset that could be of use. After returning from the conference, the geometry was created and simulations have been carried out. However, there was not enough time between the end of the conference and the end date of the project in order to carry out a thorough validation of the flow field. The PIs will continue these simulations over the course of the fall and spring semesters (as time permits) to see if good agreement with experimental data can be obtained. This project, while not very successful, initiated collaboration between the SimCenter and Sandia National Lab. Additionally, it supported the SimCenter's swimming lane related to "Energy & Environment". The future for this kind of alternate energy research is uncertain because of the changes in the political climate at the federal level.

Lead PI	Dr. Craig Tanis
Co-PI(s)	Dr. Kidambi Sreenivas
Other Personnel	None
Project Title	Optimizing FUNSAFE for Leadership-Class Machines
Award Start – End Date	July 1, 2016 – July 31 2017
Summary	The goal of this project was to update the SimCenter-developed finite element code, FUNSAFE, optimizing it for GPU-enabled supercomputing systems, and getting a large case to run on the Titan system at Oak Ridge National Lab. Over the course of the project, we switched to focusing on the SimCenter's new GPU-based system. Impressive performance results for parts of FUNSAFE were achieved, but the full port is incomplete. We (Dr. Tanis as Co-PI) have been awarded external funding to continue this work, including an update of the code to use the Kokkos framework for performance portability.

Lead PI	Dr. Robert Webster
Co-PI(s)	None
Other Personnel	Dr. Kidambi Sreenivas Dr. Ethan Hereth Mr. David Collao
Project Title	Numerical Simulations of Axial Compressor Flow Fields Employing Higher-order Accuracy
Award Start – End Date	July 1, 2016 – June 30, 2017
Summary	The major objective was to make use of higher-order spatial accuracy in the simulations of an axial compressor, for which there was a reasonable experience base using standard (i.e., 2nd order) spatial accuracy. Thus, one-to-one comparisons could be made, especially with regard to comparison of the numerical results with experimental results in terms of overall performance parameters. The original plan was to use both finite-volume and finite-element methodologies with higher-order spatial accuracy and make comparisons between the two methodologies, as well as with experiment. In the end, only the finite-volume methodology was tested, since it was "ready to use," at least as applied to rotating machinery. Even so, this was a useful experience as it provided clear evidence that the use of higher-order spatial accuracy improved the agreement with experiment.

Lead PI	Dr. Dalei Wu
Co-PI(s)	Dr. Yu Liang Dr. Li Yang Dr. Farah Kandah Dr. Joseph M. Kizza
Other Personnel	*Identify by type – senior personnel, technicians, graduate students, undergraduate students* Mehran Ghafari, Maxwell Omwenga, Stuart Eudaly, Nada Alharbi, Sharmila chackrawathy, Maha Almaimani, Rabhu Bajracharya - Graduate students Robert Slaughter, Dakila Ledesma, Christopher Davis, Alaykumar Patel, Suhail Arora, Austin Obyrne, Peter Zeglen, Derek Snyder, Morgan Sanborn, Izabella Arredondo - Undergraduate students
Project Title	Multiscale Serviceability Analysis and Assessment of Urban Infrastructure
Award Start – End Date	July 1, 2016 – June 30, 2017

Summary	The project was primarily targeted at developing a new multi-scale structural health monitoring system over Big-Data platform (MS-SHM-BD) to monitor and evaluate the serviceability of large-scale civil structures. Under the sponsorship of CEACSE funding, the team has been able to complete the major research goals and tasks of the project. The impacts are as follows: • Two research seminars on the project were given in SimCenter seminar series by the team faculty in early 2017. Research findings were also presented during UTC Research Dialogues 2017. • A total of 7 graduate students (3 females) and 10 undergraduate students (2 females) have been involved in the project. • Four research papers have been published, including one book chapter, two journal papers, and one conference paper. A female graduate student is the first author of the conference paper. In addition, two conference papers have been submitted and two journal papers are under preparation by the team. • The team has submitted four research proposals to NSF, NIST, and NIHS, with one proposal being funded by NSF (#1647175, $299,884). • Collaborations have been established with researchers from inside and outside UTC. The team submitted research proposals by collaborating with professors and researchers from University of Vermont, University of Cincinnati, University of Tennessee at Knoxville, Old Dominion University, Oak Ridge National Laboratory, and UTC Math Department. • With the help of The Enterprise Center, The team also held meetings with officials and engineers from local organizations, including Tennessee American Water, EPB, Chattanooga Department of Transportation, and Chattanooga Public Works, for experiment planning and demonstration.

2017 Project Accomplishments, Outcomes, and Impacts

As noted above, in FY2017 CEACSE awarded new seed funding to support the research activities of sixteen faculty members for twelve new projects from various disciplines across computational science and engineering. CEACSE continued its efforts to broaden the scope of research through increased participation of additional faculty, graduate students, and undergraduate students.

The funded projects key to the five priority areas: Aerospace and Defense (five projects), Energy & Environment (two projects), Urban Science (three projects), Health & Biosystems (one project), and Manufacturing (one project). Additionally, certain projects have elements that cross-cut multiple areas, such as Urban Science plus Energy & Environment.

We have highlighted many aspects of those successes in the foregoing, including highlights of new funding, and student impacts. Appendix B provides the full reporting on each of the grants, including detailed final reports articulating the accomplishments, outcomes, and impacts for each award.

In addition, the second part of Appendix B provides the final reports of six projects that CEACSE supported prior to FY2017, but which were completed by June 30, 2017.

Goals & Future Plans

FY2017 Awardee Goals & Future Plans

In their final reports, awardees were asked to address their goals and future plans for their research. Information from each awardee is included in Appendix B.

CEACSE Goals & Future Plans

The Center of Excellence in Applied Computational Science and Engineering (CEACSE) catalyzes innovative research across disciplines, supporting scientific inquiry and enabling discovery through computation. The mission of CEACSE is to establish expand, and sustain a cohesive multidisciplinary effort in applied computational science and engineering that is leveraged across UTC to produce sustained growth in research funding, excellence in integrated education and research, and to increase national and international stature and competitiveness in Tennessee.

Grounded in this mission, CEACSE's goals are being met by a combination of funding of peer-reviewed research, and by strategic investment in advanced computational facilities. In FY2017, $250,000 of CEACSE funds and $100,000 of UC Foundation support funding was jointly invested in a new computational cluster, described elsewhere in this report. That investment has already been leveraged by new funding in Aerospace/Defense, as well as pending funding in Aerospace/Defense.

Consonant with these goals and UTC's vision for the SimCenter, the 2017-2018 CEACSE grant competition cycle included a strong focus on research in the fields of Urban Science, Energy & Environment, Defense & Aerospace, and Biomedical research. Funds were awarded to proposals that will result in high-impact peer reviewed publications and "seed" larger, long-term extramural funding. For FY 2018 a total of $684,342 was awarded to nine lead principal investigators and twelve collaborating investigators across eight different departments.

The remaining CEACSE funds for FY2017-18 will be devoted to strategic investments in two areas: a new high performance storage system (approximately 1 PB of usable storage) to support the recently acquired HPC cluster and to replace a seven-year old HPC storage system, at a cost of approximately $475,000 ($375,000 of CEACSE funds, and $100,000 of UC Foundation support dollars), and approximately $250,000 on added computational power in the form of new IBM Power9 servers with NVIDIA GP-GPU nodes capable of supporting much higher sustained performance for high performance flow solvers, machine learning, and analytics. These systems also mirror the exact architecture being installed as "Summit" at ORNL in their 200+ Petaflop machine this fall; others such as SpaceX use Power architecture cluster nodes for their high-end simulations. Availability of this superior and distinct architecture, with multiple V100 GP-GPUs per node, will allow UTC scientists further to advance their studies of performance-portable solvers for hypersonic and turbomachinery systems, and better prepare their solvers for the next generation of pre-Exascale leadership class machines at ORNL, LLNL, DOD labs, and elsewhere. (Notably, the Power architecture is not available through NSF XSEDE.)

The following awardees and projects will support CEACSE's strategic goals and future plans in the 2017-18 fiscal year[3]:

Dr. Feng Bao, Lead PI, in collaboration with Dr. Kidambi Sreenivas and Dr. Jin Wang.
"Computational Modeling and Uncertainty Quantification for Wave Energy"
Award Amount: $84,771.00

> Ocean waves, generated by wind blowing over the water surface, have tremendous energy which can be captured and converted into electricity. With the rising demand for energy, growing consumption of oil and gas, and increasing global warming, waves offer an attractive green energy source and have generated considerable interest in research, development and testing in recent years. The research carried out in this work focuses on deriving mathematical and computational methods which describe structure motions that occur between ocean wave, wind wave and solid energy converters. The research activities conducted in this project will establish interdisciplinary collaborations between the Department of Mathematics and the SimCenter at UTC, and will also build a research direction for future students in the Ph.D. program in Computational Science with a concentration in Computational Mathematics within Department of Mathematics.

Dr. Bradley Harris, Lead PI, in collaboration with Dr. David Giles and Dr. Ethan Hereth.
"A Computational Study of the Impact of Exogenous Fatty Acid Substitutions on the *Vibrio cholerae* Outer and Inner Membranes"
Award Amount: $27, 481

> Food and waterborne enteric pathogens kill approximately 2 million people each year, and the ways in which these organisms uptake and utilize fatty acids are critical to their ability to spread disease. One of the most extensively studied of these pathogens is *Vibrio cholerae*, the Gram-negative bacterium responsible for the acute intestinal infection known as cholera. The ability of this pathogen to uptake fatty acids from its environment may contribute to its ability to survive as it passes through the human gastrointestinal tract. The objective of this project is to build computational models to further our understanding of the structure and function of bacterial membranes and provide new insights relevant to the prevention and treatment of this disease. This project fosters collaboration among researchers in biology, chemical engineering, and computational science. The combined results of this study will serve to establish this research team as investigators in the field, and

[3] All funded projects were subject to an initial internal review and down select based on internal assessments, followed by a second round of evaluation through external peer review, and concluded by internal panel selection in which the external peer reviews were the driving factor determining final selection of the awardees.

will be used to support the pursuit of external funding through agencies such as the National Institutes of Health and the National Science Foundation.

Dr. Hope Klug, Lead PI, in collaboration with Dr. Jennifer Boyd and Dr. Hong Qin.
"The Development and Application of Computational Tools to Address Fundamental Questions in Ecology and Evolution"
Award Amount: $88,998

In recent years, funding agencies and journals have required researchers to place data in depositories, which has led to large datasets that can potentially be used to answer fundamental biological questions about the astounding diversity of life in relation to interactions among organisms and their environment (i.e., ecology) and changes across generations in the genetic and phenotypic makeup of populations (i.e., evolution) on a broad scale. We will develop and utilize novel computational tools that allow us to effectively analyze large datasets extracted from biological databases to investigate the link between biological traits and species' rarity, as well as climate change vulnerability. We will also investigate how life-history traits, ecological conditions, and sociality interact to influence mating and parental dynamics. The proposed research will allow us to utilize high performance computing resources to address pressing questions in ecology and evolution, expand the research programs in two departments and colleges and allow non-computer scientists to collaborate with a computer scientist. This work will lead to high-impact publications and grant submissions, and facilitate the research training of numerous undergraduate and graduate students.

Dr. Soubantika Palchoudhury, Lead PI, in collaboration with Dr. Abdollah (Abi) Arabshahi.
"Computational Fluid Dynamic Approach to Predict Transport and Distribution of Nanodrugs"
Award Amount: $89,221

Nanodrugs are seen as a next-generation solution in the field of biomedicine, particularly for their use as chemotherapeutic and drug delivery agents. The key advantage of nanodrugs is their ability to selectively reach the diseased site without affecting healthy tissues. In nanomedicine, a computational approach is used to predict the transport and distribution profile of nanodrugs inside the body, but the method is still in its developmental stages. Transport of nanodrugs is a complex process due to the combined involvement of hydrodynamic forces, chemical interaction of the surface, magnetic attraction, adhesion to the cell wall, and Brownian forces. The goal of this project is to develop a robust computational fluid dynamics model for predicting the transport of a new Pt-iron oxide nanodrug synthesized at CECS, and to determine the factors dominating the drug's transport. The project will put the SimCenter at the forefront of emerging innovation in the field of Health and Biological Systems. In addition, the project has tremendous potential for publication in high-impact journals like Nano Letters, Chemical

Communications, and ACS Nano due to its novelty. This research will also serve to provide preliminary data for extramural funding opportunities.

Dr. Hong Qin, Lead PI, in collaboration with Dr. Craig Tanis.
"Connecting the Control Theory of Engineering to a Network Theory of Cellular Aging in Biology"
Award Amount: $91,906

In Engineering, control theory studies how a system can be tuned to desirable behavior with given input through feedback. Applying control theory to gene networks is a promising new direction in systems biology and precision medicine because it can improve targeted gene therapies. We recently developed a network model for cellular aging which uses the same graph models with network control studies. We propose to apply network control theory in our gene network model of cellular aging, thereby identifying critical genes and gene interactions required for longevity. Methods developed through this pilot project will establish UTC in an important new research direction on complex networks and will enhance research across disciplines on campus.

Dr. Donald Reising, Lead PI, in collaboration with Dr. Daniel Loveless.
"Unlocking the Secrets of RF-DNA Fingerprinting"
Award Amount: $91,978

Wireless communication networks are seamlessly used to not only by individuals to conduct personal communication, but also by businesses to carry out daily operations that are essential to their success. Therefore, it is imperative that these networks employ sufficient security measures essential to providing a trusted exchange of information while simultaneously protecting and safeguarding both users and associated information. Digital techniques such as encryption and authentication are commonly attacked and compromised and they fail to leverage the naturally occurring discriminatory information contained within the wireless waveforms themselves. Radio Frequency (RF) fingerprinting is one technique that has been developed to leverage such discriminatory information as a means of enhancing wireless network security. However, the relationship between the RF hardware components and the exploited distinct and native attributes remains unexplored, because researchers traditionally treat this collection of components as a "black box" with little to no thought as to how they contribute and/or possibly hinder RF fingerprinting. The proposed effort looks to open the "black box" and investigate the connection between the waveform distinct and native attributes exploited by the RF fingerprinting process, and the hardware components that are used in the construction of the wireless device. This work is integral to the development of secure wireless communication networks that will be deployed throughout the smart and connected communities of the future.

Dr. Mina Sartipi, Lead PI, in collaboration with Dr. Farah Kandah and Dr. Zhen Hu.
"Enabling Wireless 3C Technologies for Smart and Connected Cities"
Award Amount: $92,000

> There is an unstoppable trend sweeping the globe for smart and connected cities (S&CCs) that are increasingly revolutionizing our lives, with enormous benefits. In order to achieve S&CCs, we need a powerful infrastructure/backbone to facilitate high-performance data transmission, data analysis, and data storage in the Age of Big Data. Due to the prevalence of mobile/Internet-of-Things devices and emerging applications, wireless technologies and mobile communications plays an irreplaceable role. Thus, by combining data with mobility, we propose to design a fundamental wireless infrastructure and to promote novel wireless 3C (Communication, Computing, and Caching) technologies to support the whole data ecosystem in S&CCs. The proposed infrastructure will enable multiple heterogeneous radio access technologies and hierarchical computing/caching modalities. Our proposed research will exploit the state-of-the-art mathematical programming and big data analytics and leverage the theoretical/applied computational science and engineering in the S&CCs design, development, and optimization. Our achievements can contribute to the advancement of 5G technologies and foster the further study on future wireless. Meanwhile, our research can attract the extensive collaborations among academic scholars, industrial partners, and community stakeholders, and have a great potential to transform Chattanooga, TN from Gig City to Wireless Gig City, and eventually to a truly smart and connected city by taking advantage of EPB's gigabit fiber optics in Chattanooga.

Dr. Kidambi Sreenivas, Lead PI, in collaboration with Dr. Abdollah (Abi) Arabshahi.
"Development of Computational Aeroacoustics Capability for Aerospace/Defense Applications"
Award Amount: $68,085

> Noise from various sources is a part of everyday life. The ability to simulate the generation and propagation of noise is a significant challenge. This is primarily because acoustic waves are a perturbation (very small changes) of the ambient pressure. Consequently, significant computational resources are needed in order to resolve these waves accurately. A recent advance in high-order algorithms enables one to increase the order of accuracy (instead of or in addition to increasing spatial resolution) locally. This could have significant implications for acoustic wave propagation as it could drive down the cost of these simulations. The proposed research will focus on applying high-order techniques to canonical and practical problems in aeroacoustics.

Dr. Endong Wang, Lead PI, in collaboration with Dr. Neslihan Alp.
"Robust Multifactor Framework for Large-scale Fault Detection and Diagnosis in Energy Systems of the U.S. Commercial Buildings"
Award Amount: $49,902

In the U.S., existing commercial buildings, such as shopping centers, office buildings, and warehouses account for around 38% of the total energy consumed. Reducing energy usage through various renovation measures in commercial buildings is an important opportunity to substantially reduce energy use and thereby mitigate possible environmental deterioration. Accurately identifying the sources contributing to energy loss and waste of building energy systems is the first step to reduce energy consumption. Fault detection and diagnosis remains a significant challenge in the domain due to the complexity of building energy systems. Energy benchmarking, which essentially contrasts a target building against referential peers to locate deficiencies, has been frequently adopted in both academia and industry to identify energy system faults that can be addressed through building renovation. Existing multi-criteria benchmarking procedures tend to ignore the inherent interactions between factors or subsystems, e.g. occupants and building structures, which could lead to serious decision errors. We have performed some work to improve this issue for residential buildings. Combining information theory, this proposed project intends to further expand our model to a generalized framework by overcoming algorithm deficiencies to become more functional. It aims at developing an efficient energy decision analysis instrument which we expect will facilitate retrofitting both locally and nationally to lower energy use in commercial buildings.

<u>BUDGET</u>

NEW AWARDS FY 2017				
Investigators	**Project Title**	**CEACSE Priority Area**	**Amount Awarded**	**Amount Expended**
Dr. Nur Sisworahardjo Dr. Abi Arabshahi Dr. Kidambi Sreenivas	Near Real-Time Detection of Anomalous Power Consumption in Smart Power Distribution Networks	Energy / Environment	$96,477	$88,469
Dr. Kidambi Sreenivas Dr. Robert Webster Dr. Abi Arabshahi	Towards Simulation of Vertical Axis Wind Turbines in Offshore Settings	Energy / Environment	$96,573.00	$92,095
Dr. Don Reising Dr. Mina Sartipi Dr. Daniel Loveless	Smart Buildings through Smarter Models	Energy / Environment	$99,753.00	$85,506
Dr. James Newman Dr. Kidambi Sreenivas Dr. Robert Webster Dr. Abi Arabshahi	FUNSAFE Framework Development for Enhanced Multidisciplinary and Multiphysics Simulations	Aerospace / Defense / Crosscutting	$94,087.00	$87,971
Dr. Craig Tanis Dr. Kidambi Sreenivas	Optimizing FUNSAFE for Leadership-class Machines	Aerospace / Defense / Crosscutting	$86,741.00	$69,936
Dr. Abdollah Arabshahi Dr. Robert Webster Dr. Kidambi Sreenivas	Computational Simulations of the Aerothermal Environment of Hypersonic Fight Vehicles	Aerospace / Defense / Crosscutting	$97,859.00	$92,465
Dr. Daniel Loveless Dr. Kidambi Sreenivas	Modeling Space and Defense Environmental Effects in Emerging	Aerospace / Defense	$25,213.00	$21,632

	Integrated Circuit Technologies			
Dr. Robert Webster Dr. Kidambi Sreenivas Dr. Abi Arabshahi	Numerical Simulations of Axial Compressor Flow Fields Employing Higher-Order Accuracy	Aerospace / Defense	$24,140.00	$23,916
Dr. Greg Heath Dr. Mina Sartipi Dr. James Newman	Intelligent Urban Planning	Urban Science	$97,942.00	$85,343
Dr. Mina Sartipi Dr. Craig Tanis	Smart Urban Connectivity Powered by Mobility-on-Demand Public Transportation and Citywide Public Communications	Urban Science	$95,503.00	$95,503
Dr. Dalei Wu Dr. Yu Liang Dr. Li Yang Dr. Farah Kandah Dr. Joseph Kizza	Multiscale Serviceability Analysis and Assessment of Urban Infrastructure	Urban Science	$95,610.00	$84,580
Dr. Trevor Elliott	Investigation of Resources and Planning for an Advanced Manufacturing Applications Center at UTC	Manufacturing	$24,300	$17,414

Awards Extended from Previous Award Periods into FY 2017				
Investigators	**Project Title**	**CEACSE Priority Area**	**Amount Awarded**	**Amount Expended**
Dr. Robert Webster	Computational Simulation of a Blow-Down Tunnel for Turbine Testing at Purdue	Aerospace / Defense	$80,591	$79,849
Dr. Abi Arabshahi	Numerical Simulation of Airflow in the Small Human Airways	Biomedical	$100,577	$97,301
Dr. Mina Sartipi	Sensing Communications and Analysis in Smart Grid	Urban Science	$59,500	$59,500
Dr. Nesli Alp & Dr. Endong Wang	Energy Performance of Residential Building Using Simple-Normalization Based Two-Stage Data Envelopment Analysis	Urban Science	$91,000	$88,105
Dr. Farah Kandah	Quality of Service Assurance Using GENI	Computational Science	$65,000	$64,953
Dr. Farah Kandah	A Robust Network Design in Cognitive Radio Networks	Computational Science	$45,000	$44,035
Dr. Joseph Kizza	Trust Propagation and Distrust in Web of Trust and Airborne Networks Authentication	Computational Science	$50,000	$49,291

Schedule 7

CENTERS OF EXCELLENCE ACTUAL, PROPOSED, AND REQUESTED BUDGET

Institution: UT Chattanooga

Center: Center of Excellence in Applied Computational Science & Engineering

	FY 2016-17 Actual			FY 2017-18 Proposed			FY 2018-19 Requested		
	Matching	Appropr.	Total	Matching	Appropr.	Total	Matching	Appropr.	Total
Expenditures									
Salaries									
Faculty	$169,076	$313,998	$483,075	$324,000	$576,000	$900,000	$204,900	$395,100	$600,000
Other Professional	$21,531	$39,987	$61,519	$36,000	$64,000	$100,000	$34,150	$65,850	$100,000
Clerical/ Supporting	$8,474	$15,737	$24,211	$18,000	$32,000	$50,000	$10,245	$19,755	$30,000
Assistantships	$31,834	$59,121	$90,955	$54,000	$96,000	$150,000	$34,150	$65,850	$100,000
Total Salaries	$230,916	$428,843	$659,759	$432,000	$768,000	$1,200,000	$283,445	$546,555	$830,000
Longevity (Exclude from Salaries)	$1,175	$2,183	$3,358	$2,880	$5,120	$8,000	$1,708	$3,292	$5,000
Fringe Benefits	$49,902	$92,674	$142,576	$108,000	$192,000	$300,000	$71,715	$138,285	$210,000
Total Personnel	$281,993	$523,700	$805,693	$542,880	$965,120	$1,508,000	$356,868	$688,132	$1,045,000
Non-Personnel									
Travel	$10,277	$19,086	$29,362	$18,000	$32,000	$50,000	$13,660	$26,340	$40,000
Software	$3,319	$6,164	$9,483	$9,000	$16,000	$25,000	$5,122	$9,878	$15,000
Books & Journals	$0	$0	$0	$0	$0	$0	$0	$0	$0
Other Supplies	$13,419	$24,921	$38,339	$12,600	$22,400	$35,000	$8,538	$16,462	$25,000
Equipment	$63,644	$118,195	$181,839	$9,000	$16,000	$25,000	$5,809	$10,789	$16,598
Maintenance	$0	$0	$0	$0	$0	$0	$0	$0	$0
Scholarships	$14,603	$27,120	$41,723	$36,000	$64,000	$100,000	$17,075	$32,925	$50,000
Consultants	$0	$0	$0	$0	$0	$0	$0	$0	$0
Renovation	$0	$0	$0	$0	$0	$0	$0	$0	$0
Other (Specify):			$0			$0			$0
Print	$136	$252	$388	$143	$267	$410	$0	$0	$0
Other Personal Services	$11,917	$22,131	$34,048	$8,750	$16,250	$25,000	$5,250	$9,750	$15,000
Membership	$75	$139	$215	$175	$325	$500	$0	$0	$0
Cost Sharing	-$19	-$35	-$53	$0	$0	$0	$0	$0	$0
Group Arranged Events	$148	$275	$422	$163	$303	$466	$0	$0	$0
Special Commercial Services	$2,333	$4,332	$6,665	$0	$0	$0	$0	$0	$0
Total Non-Personnel	$119,851	$222,580	$342,431	$93,831	$167,545	$261,376	$55,454	$106,144	$161,598
GRAND TOTAL	$401,843	$746,281	$1,148,124	$636,711	$1,132,665	$1,769,376	$412,322	$794,276	$1,206,598
Revenue									
New State Appropriation		$744,983	$744,983		$762,855	$762,855		$800,998	$800,998
Carryover State Appropriation		$376,554	$376,554		$375,256	$375,256			$0
New Matching Funds	$405,600		$405,600	$405,600		$405,600	$405,600		$405,600
Carryover from Previous Matching Funds	$221,908		$221,908	$225,665		$225,665			$0
Total Revenue	$627,508	$1,121,537	$1,749,045	$631,265	$1,138,111	$1,769,376	$405,600	$800,998	$1,206,598

FY 2017 Publications And Presentations Of CEACSE Seed Funded Research

National and International Conference Proceedings

1. Sisworahardjo: One paper was submitted and accepted for 2017 International Conference on High Voltage and Power System. Another paper is in preparation for possible publication in conference/journal.
2. Sreenivas, K., Webster, R.S., and Hereth, E.A., "Impact of High-Order Spatial Accuracy on Multi-Stage Turbomachinery Simulations," AIAA-2017-4823, 53rd AIAA/SAE/ASEE Joint Propulsion Conference, 10 – 12 July, 2017, Atlanta, GA.
3. N. Alharbi, Y. Liang, and D. Wu, "A Data Preprocessing Technique for Gesture Recognition Based on Extended Kalman Filter," The BIGDATA4HEALTH Workshop, July 2017.
4. F. Kandah and J. Whitehead, "Cluster-Based Dynamic Backup in Cognitive Radio Networks," 2017 International Conference on Computing, Networking and Communications (ICNC), Santa Clara, CA, 2017, pp. 740-744.

Publications

1. Y. Liang, D. Wu, and et al., "Civil Infrastructure Serviceability Evaluation Based on Big Data," Guide to Big Data Applications, Springer, Editor: S. Srinivasan. Dec. 2016. Book chapter.
2. Y. Liang, D. Wu, and et al., "Big Data-enabled Multiscale Serviceability Analysis for Aging Bridges," Digital Communications and Networks, Elsevier, Volume 2, Issue 3, July 2016.
3. S. Guo, H. Zhang, P. Zhang, D. Wu, and D. Yuan, "Generalized 3-D Constellation Design for Spatial Modulation," IEEE Transactions on Communications, Vol. 65, No. 8, Aug. 2017. Journal impact factor: 4.058.
4. Kizza, Joseph. M. Fiege-Fiat-Shamir Revisited. Journal of Computing and ICT Research, Vol. 4, No. 1, pp. 9-19. http://www.ijcir.org/volume4-number1/article2.pdf.
5. Kizza, Joseph M. Data Transfer Speed up in the Revised Feige-Fiat-Shamir ZKP Protocol, Technical Report – TR-09-2, USAF Research Laboratory, Rome, NY.
6. Farah Kandah, Steven Schmitt, and Jesse Whitehead, "Using Hybrid Spectrum Handoff Towards Fairness Usage in Cognitive Radio Networks", IJIPM: International Journal of Information Processing and Management, Accepted 2017.
7. Farah Kandah and Jesse Whitehead, "Trust-based Survivability Provisioning in Wireless Mesh
8. Networks", IJIPM: International Journal of Information Processing and Management, Vol. 7, No. 2, pp. 36 ~ 47, 2016
9. Wang E, Alp N, Shi J, Wang C, Zhang X, Chen H (2017). Multi-criteria building energy performance benchmarking through variable clustering based compromise TOPSIS with objective entropy weighting. Energy 125: 197-210. Impact Factor: 4.520

10. Wang E, Shen Z, Alp N, Barry N (2015). Benchmarking energy performance of residential buildings using two stage multifactor data envelopment analysis with degree-day based simple-normalization approach. Energy Conversion and Management, 106: 530-542. Impact Factor: 5.589

Other External Academic Activities

1. Heath et al. Physical Activity and Public Health Workshop – May 5, 2017 – PI assisted by other UTC faculty presented a workshop for professional staff of the Tennessee Department of Health Southeast Regional Office. Results from the current project were presented as examples on how public health data can be used to support the promotion of health and concept of a health community.
2. M. Sartipi, R. Thompson, "Real-Time See Through Technology for Collected Autonomous Vehicles," US Ignite Application Summit and Smart Cities Connect Conference, Live Demonstration, June 2017.
3. M. Sartipi, "Connected Autonomous Vehicles at UTC," 1st Tennessee Connected & Automated Vehicle Summit, May 2017.
4. The participated in the Global City Team Challenge (GCTC) 2016 SuperCluster Kickoff, Washington DC, October 25-26, 2016, networking with other GCTC Action Cluster team leads.
5. Dr. Wu attended the IEEE INFOCOM, Atlanta, May 1-4 2017, meeting with NSF CNS program officers.
6. D. Alp: THEC ITQ Workshop for High School Science and Math Teachers in Tennessee – June 19-23, 2017

Submissions for Additional External Funding

1. Arabshahi, Webster, Sreenivas: Member of a joint proposal (Team members are; the University of Dayton Research Institute, University of Tennessee, and Purdue University) entitled "Reusable Hypersonic Vehicle Structures," to the Air Force Research Laboratory (AFRL). Enabling Technologies for High-speed Operable System (ETHOS) federal project BAA No. FA8650-17-S-2002. $ 10,000,000 / 3 years. August 2017.
2. Loveless. CAREER: Maximizing Performance and Reliability of Advanced Electronics Technologies through Stochastic Modeling, $500,000, Mar. 2018-Apr. 2023, pending.
3. NSF "US Ignite: Collaborative Research: Focus Area 1: Fiber Network for Mapping, Monitoring and Managing Underground Urban Infrastructure," $299,884, 01/2017 - 12/2019, PI: Dalei Wu, Co-PIs: Yu Liang, Li Yang.
4. NSF "Big DATA: IA: Collaborative Research: Critical Techniques for Data-driven Monitoring of Structural Health of Bridges in the United States," Program: Critical Techniques, Technologies and Methodologies for Advancing Foundations and Applications of Big Data Sciences and Engineering, submitted in 03/2017, $617,818, PI: Yu Liang, Co-PIs: Dalei Wu, Feng Bao, Cuilan Gao.
5. NIST, "Building Fire Resilient Communities with Emerging Computing Technologies," $1,508,098, submitted in 03/2017, PI: Li Yang, Co-PIs: Dalei Wu,

Liang Yu.

6. The National Institute For Hometown Security, “Deployable Critical Infrastructure Data Viewer Incorporating Unmanned Systems Feeds,” Program: National Infrastructure Protection Plan (NIPP) Security and Resilience Challenge, $315,864, submitted in 05/2017, PI: Li Yang, Co-PIs: Joseph Kizza, Dalei Wu.
7. Title of Project: IUSE/PFE:RED: Institutional Transformation of the Computer Science Education System for the 21st Student; Source of Support: IUSE/PFE:RED; Total Award Amount: $1,387,626 (PI: Kizza)
8. Title of Project: Strengthening the National Cyber Security Workforce: SFS program at University ofTennessee at Chattanooga; Source of Support: NSF CyberCorps; Total Award Amount: $1,897,076 (Co-PI;
9. PI: Li Yang). EAGER: Curbing Crimes in Urban Areas Using Emerging Computing Technologies $280,832 (Co-PI) (PI: Dr. Li Yang).
10. US Ignite: Focus Area 1: Improving Safety in Urban Neighborhoods using Cyber Physical Systems - $596,551 (Co-PI) (PI Dr. Farah Kandah).
11. NRT-DESE: Data in the GigCity: A Unified and Comprehensive Platform for Education and Research on Data Science and Engineering to Push Revolutionary Urbanization - $2,770,752 (Co-PI), (PI: Dr. Mina Sartipi).
12. F. Kandah. NSF CAREER: Adopted Networking Design to Improve the Network Performance in Crowded and Critical Situations.
13. E. Wong. NSF PROPOSAL PREPARATION INITIATIVE--- Integrated Efficient Environmental Sustainability Modeling of Built Environments
14. E. Wong. Alfred P. Sloan Foundation---Building Energy Efficiency Analysis
15. E. Wong. CRISP--- 3D Printing Technology for Sustainable Construction
16. E. Wong. ORAU travel grant
17. E. Wong. TDOT research ideas
18. E. Wong. NSF-China---Open-Block Oriented Designing Methods and Strategy
19. NSF ITEST PROPOSAL - EXploring Clean Energy through hands-on Learning (EXCEL) Requested Budget: $1,170,501; Submitted: August 2016 ; Nesli Alp; Co-PI: Endong Wang.
20. THEC Improving Teachers Quality (ITQ) PROPOSAL - EXploring Clean Energy through hands-on Learning (EXCEL) Submitted: September 2016 Requested Budget: $73,911; PI: Nesli Alp. Funded.
21. Tennessee Board of Architecture and Engineering Examiners (TBAEE) Special Grant Submitted: October 2016 Requested Budget: $20,000; PI: Nesli Alp. Funded.
22. NSF ITEST PROPOSAL - Real-world Additive Manufacturing Projects for Underrepresented Participants (RAMP UP) Submitted: August 2017 Requested Budget: $1,005,619 PI: Nesli Alp
23. NSF Advanced Technological Education (ATE) PROPOSAL - 2+2 MET: Developing an Industry-Responsive Mechatronics AAS to BAS Pipeline for Engineering Technicians Requested Budget: $586,997’ PI: Nesli Alp

Student Activities

1. Patel, Amee M., "Development of a remote IoT laboratory for cyber physical systems" (2017). Masters Theses and Doctoral Dissertations. Available at: http://scholar.utc.edu/theses/526
2. R. Thompson, Z. Hu, J. Cho, J. Stovall, A. Harris, and M. Sartipi, “See-Through Technology Using V2X Communication,” submitted to the ACM Mid-Southeast, August 2017.

EXTERNAL FUNDING

Lead PI	Dr. Abdollah (Abi) Arabshahi
Co-PI(s)	Dr. Robert S. Webster
Project Title	Computational Simulations of the Aerothermal Environment of Hypersonic Flight Vehicles
Proposal Submissions	None
Contracts / Awards Received	None
Sponsored Program Capacity Building Activities	None

Lead PI	Dr. Trevor S. Elliott
Co-PI(s)	(Originally Jan Evans)
Project Title	Investigation of Resources and Planning for Advanced Manufacturing Applications Center (AMAC) at UT Chattanooga
Proposal Submissions	None
Contracts / Awards Received	Space within the Mapp Building on UTCs campus was provided for the establishment of this center. Currently approximate square footage is 6500 sq ft. Used funding in current/pending funding reports for grants submitted during this period. One funded grant as Key personnel from THEC for workshop on improving teacher quality during this period. One grant pending review with this grant listed a current funding.
Sponsored Program Capacity Building Activities	Did not request enough funds for hosted workshop attendance. Located workshop materials from different national funding agencies and reviewed them for potential funding applications, such as NSF MME and Cyber Manufacturing. Also located and reviewed many workshop reports (MME, Materials Innovation, Advanced Manufacturing for Smart Goods, Nano Heat and Mass Transfer, Carbon Nano Materials, etc…)

Lead PI	Dr. Gregory W. Heath
Co-PI(s)	Dr. Mina Sartipi Dr. James Newman
Project Title	Healthy and Intelligent Transportation Planning: Estimating Return on Investment Associated with Improved Infrastructure for Bicycling and Walking and Decreased Physical Inactivity in Chattanooga/Hamilton County
Proposal Submissions	None
Contracts / Awards Received	None
Sponsored Program Capacity Building Activities	Submission of a symposium proposal for the Annual Meeting of the Southeast Chapter of the American College of Sports Medicine "Potential Impact of the Built Environment on Physical Activity and Chronic Disease Prevent in Communities"

Lead PI	Dr. T. Daniel Loveless
Project Title	Modeling Space and Defense Environmental Effects in Emerging Integrated Circuit Technologies
Proposal Submissions	CAREER: Maximizing Performance and Reliability of Advanced Electronics Technologies through Stochastic Modeling, T. D. Loveless, $500,000, Mar. 2018-Apr. 2023, pending.
Contracts / Awards Received	None
Sponsored Program Capacity Building Activities	Interactions with program officers from: Defense Threat Reduction Agency (DTRA), Pauline Paki National Science Foundation (NSF), Dimitri Pavlidis, Mary Poats Participant in the Grant Writers Workshop, Grant Central Review Participant in CAREER development with the Implementation Group (TIG)

Lead PI	Dr. James C. Newman III
Co-PI(s)	Dr. Kidambi Sreenivas Dr. Robert Webster Dr. Abdollah Arabshahi
Project Title	FUNSAFE Framework Development for Enhanced Multidisciplinary and Multiphysics Simulations
Proposal Submissions	- ***University of Dayton Research Institute*, "Reusable Hypersonic Vehicle Structures." Investigators: Drs. James Newman, Abdollah Arabshahi, Robert Webster, and Ethan Hereth. [**$893,239] - *Engility Corporation (DoD HPC Modernization Program: PETTT)*, "Heterogeneous HPC for High-order Stabilized Finite-elements on Moving and Deforming Domains." Investigators: Drs. Robert Webster, James Newman, Kidambi Sreenivas, and Craig Tanis. [$422,001] - *Pointwise, Inc.*, "High Fidelity Mesh and Geometry Tools." Investigator: Dr. James Newman. [$24,975] - *NASA Langley Research Center*, "Revolutionary Computational Aerosciences (RCA) Institute Support: Visitors and Faculty Engagement." Investigator: Dr. James Newman. [$14,948]
Contracts / Awards Received	**Awards during this period of performance (from Proposal Submissions list above):** - ***University of Dayton Research Institute*, "Reusable Hypersonic Vehicle Structures." Proposal funding is in place via the AFRL Enabling Technologies for High-speed Operable Systems (ETHOS) Program. <u>Award is forthcoming</u>.** - *Engility Corporation (DoD HPC Modernization Program: PETTT)*, "Heterogeneous HPC for High-order Stabilized Finite-elements on Moving and Deforming Domains." <u>Proposal has been selected for funding</u>. - *Pointwise, Inc.*, "High Fidelity Mesh and Geometry Tools." <u>Proposal was funded</u>, contract is being put in place to receive award. - *NASA Langley Research Center*, "Revolutionary Computational Aerosciences (RCA) Institute Support: Visitors and Faculty Engagement." <u>Proposal was funded</u>. Award has been received. **Previous awards from CEACSE funded initiatives:** - *Engility Corporation (DoD HPC Modernization Program: PETTT)*, "Investigation of Unstructured Higher-Order Methods for Unsteady Flows," 9/1/14 – 8/31/15. Investigator: James C. Newman III.

	[$120,000] *Office of Naval Research*, “High Order Accuracy for Large Eddy Simulations,” 6/1/16-6/30/17. Investigators: James C. Newman III and Kidambi Sreenivas. [$117,616]
Sponsored Program Capacity Building Activities	*Sponsored Program Office Visit*, Naval Surface Warfare Center – Carderock Division. June 12 – 16, 2017.

Lead PI	Dr. Donald R. Reising
Co-PI(s)	Dr. Mina Sartipi Dr. T. Daniel Loveless
Project Title	Smart Buildings Through Smarter Models
Proposal Submissions	NSF Smart & Connected Communities (S&CC), Solicitation 16-610 https://www.nsf.gov/funding/pgm_summ.jsp?pims_id=505364 Anticipated Dates: September 2017 – Release of RFP, November 2017 – Pre-proposal submission, February 2018 – Full proposal submission.
Contracts / Awards Received	None
Sponsored Program Capacity Building Activities	Dr. Sartipi and Reising participated in “Chattanooga’s Smart City Testbed” workshop on April 4, 2017. This workshop served to connect and engage a diverse group of researchers in the challenges and research opportunities surrounding “smart” city. It focused heavily on brainstorming sessions within the areas of: Transportation, Energy, and Public Health. Dr. Sartipi and Loveless participated in a “Smart Cities” workshop in May of 2017 in Cadiz, Spain. The workshop was intended to facilitate collaboration between researchers at UCA and UTC. Additionally, local government officials were present.

Lead PI	Dr. Mina Sartipi
Co-PI(s)	Dr. Craig Tanis

Project Title	Smart Urban Connectivity Powered by Mobility-on-Demand Public Transportation and Citywide Public Communications
Proposal Submissions	NSF Smart & Connected Communities (S&CC), Solicitation 16-610 https://www.nsf.gov/funding/pgm_summ.jsp?pims_id=505364 Pending (submitted Feb. 2017) NSF Big Data Regional Innovation Hubs: Establishing Spokes to Advance Big Data Applications (BD Spokes), Solicitation 17-546 In Collaboration with GA Tech and VA Tech (to be submitted Sept. 2017) NSF Critical Techniques, Technologies and Methodologies for Advancing Foundations and Applications of Big Data Sciences and Engineering (BIGDATA), Solicitation 17-534 https://www.nsf.gov/publications/pub_summ.jsp?WT.z_pims_id=504767&ods_key=nsf17534 Anticipated submission data, spring 2018.
Contracts / Awards Received	None
Sponsored Program Capacity Building Activities	Dr. Sartipi participated in "Chattanooga's Smart City Testbed" workshop on April 4, 2017. This workshop served to connect and engage a diverse group of researchers in the challenges and research opportunities surrounding "smart" city. It focused heavily on brainstorming sessions within the areas of: Transportation, Energy, and Public Health. Through this workshop we met several faculty from GaTech, Vanderbilt, UTK, VA Tech. We have started collaborating with some of these faculties/ researchers. We are identifying more collaboration opportunities. Dr. Sartipi participated in a "Smart Cities" workshop in May of 2017 in Cadiz, Spain. The workshop was intended to facilitate collaboration between researchers at UCA and UTC. Additionally, local government officials were present. Dr. Sartipi also met with Chattanooga DOT, TN DOT, ORNL Transportation for potential collaborations. Dr. Sartipi has traveled to several NSF workshops, smart city expos and has talked with several NSF program officers regarding these opportunities. She has also talked with Planning Division director of TDOT.

Lead PI	Dr. Nur Sisworahardjo
Co-PI(s)	Dr. Abi Arabshahi Dr. Kidambi Sreenivas
Project Title	Near Real-time Detection of Anomalous Power Consumption in Smart Power Distribution Networks
Proposal Submissions	• National Science Foundation, REU Site: An Interdisciplinary CubeSat Research and STEM Education Platform at the University of Tennessee at Chattanooga (UTChattSat) • National Science Foundation, EXCEL: EXploring Clean Energy through hands-on Learning • Tennessee Department of Transportation (TDOT), Road Health Monitoring System
Contracts / Awards Received	Non-Disclosure Agreement between UTC and EPB
Sponsored Program Capacity Building Activities	Attending workshop/conference: • NSF Workshop, June 16-17, 2017, University of Minnesota, Minneapolis, Minnesota. • 8th Indonesia Focus Conference, University of Kentucky, Lexington, Kentucky, September 30 - October 1, 2016

Lead PI	Dr. Kidambi Sreenivas
Co-PI(s)	Dr. Abi Arabshahi Dr. Robert Webster
Project Title	Towards simulation of vertical axis wind turbines in offshore settings

Proposal Submissions	None related to this project. Related to other CEACSE awards: Heterogeneous HPC for High-order Stabilized Finite-elements on Moving and Deforming Domains, HPCMP, $400K
Contracts / Awards Received	Heterogeneous HPC for High-order Stabilized Finite-elements on Moving and Deforming Domains, HPCMP, $400K
Sponsored Program Capacity Building Activities	Met with Dr. Mike List and colleagues at AFRL, Wright Patterson AFB, Dayton, OH. Met with Drs. Hua Shan, Chandra Kannepalli, and Matthew Jemison at NSWC-Carderock Division, Washington, DC. Met with researchers from SmartTruck (at the SimCenter). SmartTruck is a company that designs and produces after-market drag reduction devices for Class 8 trailers. Talked to Jared Luebe of Kewit Engineering Group. They were interested in us carrying out some simulations for an LNG project they were looking to work on, though the LNG project fell through.

Lead PI	Dr. Craig Tanis
Co-PI(s)	Dr. Kidambi Sreenivas
Project Title	Optimizing FUNSAFE for Leadership-Class Machines
Proposal Submissions	CEACSE 2017-18 "Expanding FUNSAFE capability" (not awarded) PETTT "Heterogeneous HPC for High-order Stabilized Finite-elements on Moving and Deforming Domains" (Drs. Tanis and Sreenivas as Co-PI)

Contracts / Awards Received	PETTT "Heterogeneous HPC for High-order Stabilized Finite-elements on Moving and Deforming Domains" (Drs. Tanis and Sreenivas as Co-PI); Engility Corp. Funded for approximately $422,000 over two years.
Sponsored Program Capacity Building Activities	Tanis conference attendances: Supercomputing 2016 (Workshop on heterogeneous computing) PEARC 2017 (part of Regional Campus Champion leadership).
Lead PI	Dr. Robert Webster
Project Title	Numerical Simulations of Axial Compressor Flow Fields Employing Higher-order Accuracy
Proposal Submissions	"Heterogeneous HPC for High-order Stabilized Finite-elements on Moving and Deforming Domains." The proposal was for $422,001 (over two years) from the Engility Corporation.
Contracts / Awards Received	See above.
Sponsored Program Capacity Building Activities	The PI and colleague (Dr. Kidambi Sreenivas) met with Dr. Michael List, director of the compressor research facility at Wright-Patterson Air Force Base. This occurred in September, 2016. A portion of that meeting was related to this project and was likely helpful in being considered for the grant that was awarded. Also, the presentation of the conference paper listed above has sparked a renewed interest from personnel at the NASA Glenn Research Center.

Lead PI	Dr. Dalei Wu
Co-PI(s)	Dr. Yu Liang Dr. Li Yang Dr. Farah Kandah Dr. Joseph M. Kizza
Project Title	Multiscale Serviceability Analysis and Assessment of Urban Infrastructure

Proposal Submissions	• NSF "US Ignite: Collaborative Research: Focus Area 1: Fiber Network for Mapping, Monitoring and Managing Underground Urban Infrastructure," $299,884, 01/2017 - 12/2019, PI: Dalei Wu, Co-PIs: Yu Liang, Li Yang. • NSF "Big DATA: IA: Collaborative Research: Critical Techniques for Data-driven Monitoring of Structural Health of Bridges in the United States," Program: Critical Techniques, Technologies and Methodologies for Advancing Foundations and Applications of Big Data Sciences and Engineering, submitted in 03/2017, $617,818, PI: Yu Liang, Co-PIs: Dalei Wu, Feng Bao, Cuilan Gao. • NIST, "Building Fire Resilient Communities with Emerging Computing Technologies," $1,508,098, submitted in 03/2017, PI: Li Yang, Co-PIs: Dalei Wu, Liang Yu. • The National Institute For Hometown Security, "Deployable Critical Infrastructure Data Viewer Incorporating Unmanned Systems Feeds," Program: National Infrastructure Protection Plan (NIPP) Security and Resilience Challenge, $315,864, submitted in 05/2017, PI: Li Yang, Co-PIs: Joseph Kizza, Dalei Wu.
Contracts / Awards Received	• NSF (#1647175) "US Ignite: Collaborative Research: Focus Area 1: Fiber Network for Mapping, Monitoring and Managing Underground Urban Infrastructure," $299,884, 01/2017 - 12/2019, PI: Dalei Wu, Co-PIs: Yu Liang, Li Yang.
Sponsored Program Capacity Building Activities	• The participated in the Global City Team Challenge (GCTC) 2016 SuperCluster Kickoff, Washington DC, October 25-26, 2016, networking with other GCTC Action Cluster team leads. • Dr. Wu attended the IEEE INFOCOM, Atlanta, May 1-4 2017, meeting with NSF CNS program officers. • Dr. Wu participated in the Grant Writing Workshop cohort, 2017.

CONCLUSION

CEACSE continues to contribute greatly to the enhancement and expansion of significant and innovative research in computational simulation and applied computational science and engineering. Through THEC's support, CEACSE researchers effectively recognize the special opportunity afforded to UTC to provide leadership in computational applications-driven research and education needed for future competitiveness in the high-technology sector of the global economy. That factor is crucial in their recruitment, and retention, as well as professional growth toward tenure and promotion. Significantly, this funding provides a fertile ground to create nationally competitive scholars and research proposals through a peer-reviewed selection process of proposals that are significant enablers of follow-on efforts with extramural funding from NSF, DOD, NASA, NIH, among others, as well as the potential for industrial sponsorship in certain situations. Those non-federal opportunities appear to be growing with the faculty's growing intellectual property, respective regional/national reputations, and know-how.

Through this seed funding for research activities, undergraduate and graduate students are being engaged in a diverse range of topics at the cutting edge of R&D, and experience a high level of interaction and involvement with faculty. In addition, we will strengthen CEACSE outreach to pre-college students and their teachers.

CEACSE-supported initiatives have already formed the basis for several collaborations and partnerships with other institutions of higher education and with business and industry partners. A number of meaningful Memoranda of Understanding and Non-Disclosure Agreements have been executed between UTC and a variety of partners and potential sponsors to explore how CEACSE can support engineering enhancements, address regional and state priority areas, and bolster robust economic growth. Our strategic partnerships with organizations in Chattanooga and the region, such as the Enterprise Center, the CoLab, and the Chamber of Commerce have already resulted in increased NSF funds at UTC for CSE-related projects leveraging the Smart-connected GigCity status of Chattanooga.

In conclusion, advancing computational science and engineering to strengthen the education, workforce development, and R&D missions at UTC continues to be a high-value investment for the State of Tennessee and the US. The CEACSE multidisciplinary team of faculty and graduate students in collaboration with their strategic partners in Chattanooga, the region, and elsewhere has been focused on the three primary objectives for the Center listed in the introductory segment of this report, namely:

- Expand CSE capabilities at UTC;
- Support startup of new research and educational work that broadens and expands the CEACSE base of research expertise; and
- Realize appropriate return on investment by attracting new extramural funding.

We are convinced that the work accomplished in Fiscal Year 2017 and the strategic vision we laid out for the future has positioned UTC and CEACSE to continue to positively impact, enhance, and accelerate the growth and advancement of Tennessee's scientific and engineering capabilities and resources.

CONTACT INFORMATION

DR. JOANNE ROMAGNI
Vice Chancellor for Research & Dean of the Graduate School

DR. TONY SKJELLUM
Director of the UTC SimCenter
Chair of Excellence in Applied Computational Science & Engineering

DR. REINHOLD MANN
UTC SimCenter Director Emeritus

DR. JOANNE G. ROMAGNI

Dr. Joanne Romagni is the Vice Chancellor for Research and Dean of the Graduate School at The University of Tennessee in Chattanooga (UTC). Before joining UTC, she was the Associate Vice President for Research at DePaul University in Chicago, where she also served as a research fellow in the biology department. Previously, she held a variety of faculty and leadership positions in research and administration at Bucknell, St. Edwards, and St. Thomas Universities. She received her Ph.D. in plant biology from Arizona State University and conducted research as a post-doctoral plant physiologist and biochemist at the USDA-ARS in Oxford, Mississippi.

In her current role, Dr. Romagni is leading efforts at UTC to establish external and interdisciplinary research partnerships to advance the University's strategic plan. Her work is focused on developing the structures and support mechanisms to enhance and expand research across graduate and undergraduate disciplines at UTC. Under her leadership, proposal dollars requested have increased by 20% while external awards are up by nearly 10% compared to FY15, including an NSF CAREER award - a major milestone for UTC. She has worked to initiate and administer more than $1,035,000 in internal grant awards in FY16.

Dr. Romagni approaches her work with a dedication to synergistic collaboration and strives to provide opportunities to underrepresented individuals. She personally mentored over 75 students in her previous lab, 80% of which were either women and/or Hispanic students. She has developed strong relationships and has extensive experience working with major grant making agencies, having served on numerous federal review panels. She was awarded funds for her own research from the National Science Foundation for her work as a PI developing an international research program for undergraduates. She has been invited by the Association of American Colleges and Universities and the International Conference of Education, Research and Innovation to speak about her expertise and success integrating undergraduate research into curricula.

DR. ANTHONY SKJELLUM

Dr. Anthony (Tony) Skjellum received his BS, MS, and PhD Degrees from Caltech. His PhD work emphasized portable, parallel algorithms and software for simulation, with a specific emphasis on message-passing systems. After graduating in 1990, he worked at the Department of Energy Lawrence Livermore National Laboratory (LLNL) for 2.5 years as a computer scientist emphasizing performance-portable message passing and portable parallel math libraries. From 1993-2003, he was on faculty at Mississippi State University, where he and his students co-developed MPICH with Argonne National Laboratory, the first implementation of the now-pervasive Message Passing Interface (MPI-1) standard. Skjellum was a leading participant in MPI-1 and MPI-2 standards as well, with specific contributions to the concepts of "groups contexts, and communicators," which stemmed from his PhD research. His work on MPI has made broad impact on all High Performance Computing (HPC) worldwide through the MPICH implementation and further R&D on MPI over the past 25 years.

From 2003-2013, he was professor and chair at the university of Alabama at Birmingham (UAB), Dept. of Computer and Information Sciences, where he continued work on high performance computing and cyber. During his tenure at UAB, he co-founded the university-wide center – Center for Information Assurance and Joint Forensic Sciences (CIA-JFR), together with Justice Science and Business leaders. This highly funded center was able to attract world-class cyber-security and forensics researchers, and spin-off a startup company, Malcovery, which was later acquired by PhishMe and still has a growing presence in Birmingham as of Fall 2017. In July 2014, he was appointed the Lead Cyber Scientist for Auburn University and Cyber Center director. He led the R&D in HPC and cyber at Auburn University in the college of engineering for just over three years prior to joining the University of Tennessee at Chattanooga in August, 2017 as a Professor of Computer Science, Chair of Excellence, and as the new SimCenter Director.

Skjellum's current research group is a split between cyber/Internet of Things, and High Performance Computing and Exascale Storage. FA-MPI is Skjellum's second implementation of a resilient MPI; he and students and his company, MPI Software Technology, previously designed and published MPI/FT, a fault-aware MPI based on MPI/Pro, a commercial MPI licensed from the mid-1990's through mid-2000's. He has current funding from DOE/NNSA and NSF. He is a senior member of ACM and IEEE, and Associate Member of the American Academy of Forensic Science (AAFS), Digital & Multimedia Sciences Division. Skjellum remains active in the MPI Forum (in multiple working groups), and is the former chair of the Object Management Group (OMG) High Performance Embedded Working Group as well, in which he remains actively involved as a standards designer and standardizer for high performance embedded signal and image processing libraries and related application programmer interfaces.

DR. REINHOLD C. MANN

Dr. Reinhold Mann is the Interim Director Emeritus of the SimCenter at The University of Tennessee in Chattanooga (UTC), a center of excellence in applied computational science and engineering. His work includes engaging faculty across UTC in the strategy development for the SimCenter as a core capability in modeling, simulation and high-performance computing, and ensuring that the strategy is executed and remains relevant.

Dr. Mann has a part-time appointment as Senior Scientist at StrataG LLC, a small business in Knoxville, TN, that provides services to help solve complex energy and environmental challenges. Dr. Mann retired on June 30, 2014 from his position as Associate Laboratory Director for Environmental, Biological and Computational Sciences at the Brookhaven National Laboratory (BNL), where he was responsible for R&D programs in biology, biotechnology, climate science, and computational science and related efforts.

Before joining BNL, Dr. Mann was the Senior Vice President for Research and Development at Battelle Science and Technology Malaysia Sdn. Bhd. in Kuala Lumpur, Malaysia. He moved to this position in November 2008 after leading the Biological and Environmental Sciences Directorate and Program at the Oak Ridge National Laboratory through a five-year period of transformational change with respect to research programs, infrastructure and capability renewal.

Dr. Mann’s research has been at the intersection of the physical and computational sciences with the life and environmental sciences. He has been leading multi-disciplinary R&D teams since 1986 and developed several R&D efforts in intelligent robotics, human-machine interactions, advanced information processing, computational biology, bioinformatics, systems biology and bioenergy. Dr. Mann served as Chairman of the Board of Directors for the US Department of Energy Bioenergy Science Center in 2007 and 2008, and was a Senior Consultant to the Director of the Oak Ridge National Laboratory from November 2008 through June 2010. Dr. Mann was a member of the Board of Directors for the NASA National Space Biomedical Research Institute, and a member of the Board of Directors for the Laufer Center for Physical and Quantitative Biology at SUNY Stony Brook, from 2011 to 2014. Since June 2015, he has been a member of the Board of Directors for Genera Energy Inc., Vonore TN, a company delivering integrated biomass supply chain solutions. He is a Senior Member of the IEEE, and member of the APS and the AAAS.

APPENDIX A

Faculty Biosketches

Abdollah (Abi) Arabshahi, Ph.D.

Research Professor	tel: (423) 425-5485
Department of Mechanical Engineering and SimCenter University of Tennessee at Chattanooga Chattanooga, TN 37403	fax: (423) 425-5229 Abi-Arabshahi@utc.edu http://www.utc.edu

Professional Preparation:

Mississippi Sate University	Starkville, MS	Civil Engineering	B.S.	1982
Mississippi Sate University	Starkville, MS	Aerospace Engineering	M.S.	1985
Mississippi Sate University	Starkville, MS	Aerospace Engineering	Ph.D.	1989

Appointments:

2005 – Present	Research Professor University of Tennessee at Chattanooga
2002 – 2005	Associate Research Professor University of Tennessee at Chattanooga
1998 – 2002	Senior Research Associate Applied Research Laboratory, The Pennsylvania State University
1996 – 1998	Research Engineer II, Computational Fluid Dynamics Laboratory, NSF/ERC for Computational Field Simulation, Mississippi State University
1991 - 1996	Research Engineer I, Computational Fluid Dynamics Laboratory, NSF/ERC for Computational Field Simulation, Mississippi State University
1989 – 1991	Post-doctoral Fellow, Computational Fluid Dynamics Laboratory, NSF/ERC for Computational Field Simulation, Mississippi State University

Book:

Whitfield, D. L., Taylor, L. K., Beddhu, M., and Arabshahi, A., "Discretized Newton- Relaxation Solution of the Three-Dimensional Unsteady Incompressible Navier-Stokes Equations," *Frontiers of Computational Fluid Dynamics,* Chapter 28, pp. 575-594, D. A. Caughey and M. M. Hafez, Editors, ISBN 0-471-95334-2, John Wiley & Sons, Ltd., New York, 1994.

Five Products Most Relevant to Proposal*:*

1. Hasbestan, J.J., Newman III, J.C., and Arabshahi, A., "Least Squares Spectral Element Method For Laminar Compressible Flows," AIAA Science and Technology Forum and Exposition (SciTech 2016) San Diego, California, January 4-8, 2016.
2. Hasbestan, J.J., Newman III, J.C., and Arabshahi, A., "A New Approach to Mesh Adaptation Procedure Using Linear Elasticity for Geometries Undergoing Large Displacements," FEDSM2014-22010, Proceedings of the ASME 2014 4th Joint US-European Fluids Engineering Division Summer Meeting and 11th International Conference on Nanochannels, Microchannels, and Minichannels, Chicago, Illinois, August 2014.
3. Arabshahi, A., Webster, R. S., Sreenivas, K., Hyams, D. G., and Whitfield, D. L., "Numerical Simulation of Reacting and Non-reacting Nozzle Flows," AIAA-2009-4858, the 45th AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit, Denver, CO, August, 2009.
4. Arabshahi, A., Sreenivas, K., Nichols, D.S., Mitchell, B. C. J., Taylor, L. K., and Whitfield, D. L., "Computational Analysis of Turbulent Internal Flow in Ballistic Solid Rocket Motors,"AIAA-2007-1449, the 45th AIAA Aerospace Sciences Meeting and Exhibit, Reno, NV, January 8-11, 2007.

5. Arabshahi, A., Janus, J. M., "A Multiblock Compressible Navier-Stokes Flow Solver Applied to Complex Launch Vehicles," *AIAA Journal of Spacecraft and Rockets*, Vol. 41, No. 3, pp. 469-472,

Five Other Significant Products:

1. Arabshahi, A., Janus, J. M., "A Multiblock Compressible Navier-Stokes Flow Solver Applied to Complex Launch Vehicles," AIAA-99-3378, the 14th Computational Fluid Dynamics Conference, Norfolk, VA, June 28-July 1 1999.
2. Cox, C. F., Cinnella, P., and Arabshahi, A., "Multi-Block Calculation for Flows in Local Chemical Equilibrium," AIAA-93-2999, 24th AIAA Fluid Dynamics Conference, Orlando, FL, July 1993.
3. Pankajakshan, R., Arabshahi, A., and Whitfield, D. L., "Turbofan Flowfield Simulation Using Euler Equations With Body Forces," AIAA-98-1978, AIAA 29th Joint Propulsion Conference, Monterey, CA, June 1993.
4. Arabshahi, A. and Whitfield, D. L., "Numerical Simulation of Supersonic Unsteady Flow for Multibody Configuration," AIAA-91-0023, AIAA 29th Aerospace Sciences Meeting and Exhibit, Reno, NV, January 1991.
5. Arabshahi, A. and Whitfield, D. L., "A Multiblock Approach to Solving the Three-Dimensional Unsteady Euler Equations About A Wing-Pylon-Store Configuration," AIAA-89-3401, AIAA Atmospheric Flight Mechanics Conference, Boston, MA, August 14-16, 1989.

Synergistic Activities:

1. Reviewer for Computers and Fluids Journal: 2009-2011
2. Reviewer for International Journal for Numerical Methods in Fluids: 2007-2009, 2014-2017
3. Reviewer for Applied Mathematical Modeling Journal: 1998-2002, 2015-2017
4. SimCenter leadership role in unsteady viscous flow engineering applications, scientific computing, and structured grid technologies, including software development, integration, and management, and also facilitating teamwork to solve complex real-world engineering problems (University of Tennessee at Chattanooga)
5. SimCenter leadership role in instruct/mentor qualified and motivated undergraduate and graduate students in the UT SimCenter research program. Maintain research based interactions with students in order to facilitate their process of gaining knowledge, skills, and other aspects of professional growth in the engineering and research field. Mentor for over 65 Undergraduate Student Researchers (University of Tennessee at Chattanooga).

Neslihan Alp, Ph.D., P.E.

(a) Professional Preparation

Istanbul Technical University	Istanbul, Turkey	Engineering Management	B.S., 1989
Istanbul Technical University	Istanbul, Turkey	Industrial Engineering	M.S., 1994
University of Missouri-Rolla	Rolla, MO	Engineering Management	Ph.D., 1996

(b) Appointments

2016-Present	**Associate Dean,** Graduate Programs and Research, Department Head of Engineering Management & Technology, UC Foundation Professor, & Chattanooga Manufacturers Association Professor, University of Tennessee at Chattanooga
2014-2016	**Interim Dean**, College of Engineering and Computer Science & UC Foundation Professor, University of Tennessee at Chattanooga
2013-2014	**Associate Dean,** Graduate Programs and Research, Department Head of Engineering Management & Technology, & UC Foundation Professor, University of Tennessee at Chattanooga
2008-2013	**Assistant Dean,** Graduate Programs and Research, Department Head of Engineering Management & Technology, & UC Foundation Professor, University of Tennessee at Chattanooga
2006-2008	**Director of Engineering Management and Graduate Programs** & UC Foundation Associate Professor, University of Tennessee at Chattanooga
2004-2006	**UC Foundation Associate Professor & Tenured**, College of Engineering and Computer Science, University of Tennessee at Chattanooga
2001 – 2004	**UC Foundation Assistant Professor**, College of Engineering and Computer Science, University of Tennessee at Chattanooga
1999 – 2001	**Assistant Professor**, College of Engineering and Computer Science, University of Tennessee at Chattanooga

(c) Products

(i) Most Closely Related Products

1. **Alp, N.** & Morales, X. (2016). Managing a Corrective Action Program. 36th American Society for Engineering Management (ASEM) International Conference, Charlotte, NC on October 26-29.
2. **Alp, N.** & Mau, J. (2016). Quality through Design: A Six Sigma Approach. Portland International Center for Management of Engineering and Technology (PICMET) 2016 International Conference, Honolulu, Hawaii, September 4-8.
3. Wang, E., Shen, Z., **Alp, N.**, & Barry, N. (2015). Benchmarking energy performance of residential buildings using two-stage multifactor data envelopment analysis with degreeday based simple-normalization approach. Energy Conversion and Management Journal, 106:530-542, November.
4. **Alp, N.,** & Tsai, C. (2014). Using Industry-Sponsored Projects to Improve Outcomes. 34th American Society for Engineering Management International Conference, Virginia Beach, VA, Oct. 15-18.
5. **Alp, N.** & Manning, C. (2014). Creating a Plan for Building Information Modeling. Portland International Center for Management of Engineering and Technology 2014 International Conference Proceedings, Kanazawa, Japan, July 27-31.

(ii) Other Related Products

1. **Alp, N.** & vonWerssowetz, N. (2013). Integrated Project Development as Applied to Public Projects. Portland International Center for Management of Engineering and Technology 2013 International Conference Proceedings, San Jose, CA, July 28-Aug. 1.
2. **Alp, N.,** & Stack, B. (2012). Scope Management and Change Control Process Study for Project- based Companies in the Construction and Engineering Industries. Portland International Center for Management of Engineering and Technology 2012 International Conference Proceedings, Vancouver, Canada, July 29-Aug. 2.
3. **Alp, N.** & Mathai, R. (2010). Smart Grid: A New Approach to Advanced Power Grid and Energy Savings. 31st American Society for Engineering Management Conference Proceedings, Rogers, AR, Oct. 13-16.
4. **Alp, N.** & Raymond, D. (2010). Application of Engineering Management Principles to Human Factors Aspect of Nuclear Control Room Design. 31st American Society for Engineering Management Conference Proceedings, Rogers, AR, Oct. 13-16.
5. **Alp, N.** & McGhee, T. (2009). Meeting the Needs of the Construction Industry. 30th American Society for Engineering Management National Conference Proceedings, Springfield, MO, October 14-17.

(d) Synergistic Activities

1. Established dual degree agreements with local community colleges, such as Chattanooga State, Cleveland State, and Dalton State.
2. Established the Living & Learning Community in the College of Engineering & Computer Science and serve as the faculty advisor.
3. Led the selection of the Engineering Management master's program as one of the Best Online Engineering Graduate Programs in the nation, ranking #7 according to US News & World Report.
4. Developed new undergraduate and graduate degree programs, such as Construction Management, Data Science, through the Computer Science & Engineering Department, and the Engineering Management and construction Management minors through the Engineering Management & Technology Department.
5. Serve as the Society of Women Engineers (SWE) faculty advisor.
6. Organized the Project Lead the Way Teaching Training Program held in Memphis and Chattanooga in June and July of 2015.
7. Supported the American Society of Civil Engineers Southeast Student Conference that was hosted by the Civil Engineering Department at UTC in March 2015, impacting more than 1,000 students and faculty from 26 different universities.

Trevor S. Elliott, Ph.D.

(a) Professional Preparation

University of Tennessee, UTC	Chattanooga, TN	Mechanical Engineering	B.S., 2005
University of Tennessee, UTC	Chattanooga, TN	Mechanical Engineering	M.S., 2009
University of Tennessee, UTSI	Tullahoma, TN	Aerospace Engineering	Ph.D., 2014

(b) Appointments

2015-Present	**Assistant Professor,** Department of Mechanical Engineering, College of Engineering and Computer Science, University of Tennessee at Chattanooga
2013-Present	**Affiliate Professor**, Project Lead the Way (PLTW), University of Tennessee at Chattanooga
2012-2015	**Adjunct Faculty,** College of Engineering and Computer Science, University of Tennessee at Chattanooga
2008-2015	**Information and Technology Administrator,** College of Engineering and Computer Science, University of Tennessee at Chattanooga
2009-2010	**Web Laboratory Design Engineer,** STELLA Project, Boeing Company and NASA contract, University of Tennessee at Chattanooga
2004-2013	**Information and Technology Director,** Project Lead the Way (PLTW), University of Tennessee at Chattanooga
2005 – 2008	**Laboratory Support Engineer,** College of Engineering and Computer Science, University of Tennessee at Chattanooga
2000 – 2005	**Information and Technology Technician**, College of Engineering and Computer Science, University of Tennessee at Chattanooga

(c) Products

(i) Most Closely Related Products

1. **Elliott, T. S.**, Sluss, D. P., and Gibson, W. A., "Biglobal Stability of the Swirling Majdalani-Fist Flowfield in Solid Rocket Motors," AIAA 2017-4948, presented at 53th Annual AIAA/SAE/ASEE Joint Propulsion Conference, Atlanta, GA, July 10–12, 2017.
2. Ayres, James K., **Elliott, Trevor**, and Margraves, Charles, "Introducing Sustainability to Secondary Level Students Using Automated Tracking Solar Array," American Society of Engineering Educators (ASEE) Southeast Section Conference 2017, Accepted, to be presented by Charles Margraves at ASEE Zone 2 conference.
3. **Elliott, T. S.**, Jenkins, B., Zeineldin, R., Johnson, J., Simons, M., Godfrey, P., and Mabry, T., "Additive Manufacturing of Small Scale Rocket Grain Cartridges with Uniformly Distributed Aluminum Particles," AIAA 2016-4507, presented by Tyler Mabry at the 52nd Annual AIAA/SAE/ASEE Joint Propulsion Conference, Salt Lake City, UT, July 29, 2016.
4. True, Nick, **Elliott, Trevor**, and Margraves, Charles, "Insulation and Zero Plus Energy Buildings – Development of a Small Scale Undergraduate Lab to Investigate the Effects of Insulation on Energy Transfer Using Thermal Imaging Cameras," American Society of Engineering Educators (ASEE) Southeast Section Conference 2016, Published, presented by Nick True at ASEE Zone 2 conference.
5. **Elliott, T. S.** and Majdalani, J., "Effect of Outflow Boundary Conditions on the Stability of Cylindrically-Shaped Hybrid Rockets," AIAA 2015-3744, presented at 51th Annual AIAA/SAE/ASEE Joint Propulsion Conference, Orlando, FL, July 27–29, 2015.

(ii) Other Related Products

1. **Elliott, T. S.** and Majdalani, J., "Two-Phase Flow Stability of Cylindrically-Shaped Hybrid and Solid Rockets with Particle Entrainment," AIAA 2014-3611, for the 50th Annual AIAA/ASME/SAE/ASEE Joint Propulsion Conference, Cleveland, OH, July 28–30, 2014.
2. **Elliott, T. S.** and Majdalani, J., "Hydrodynamic Stability Analysis Of Particle-Laden Solid Rocket Motors," Journal of Physics: Conference Series, Vol. 548, 2014. Presented at the Proceedings of the 22nd International Conference on Spectral Line Shapes, Tennessee, U.S.A., June 1-6, 2014.
3. **Elliott, Trevor S.**, "Stability of Particle-Mean Flow Interactions in Solid and Hybrid Rockets," Ph.D. Dissertation, University of Tennessee Space Institute, August 2014, 95 Pages.
4. **Elliott, T. S.**, Batterson, J. W., and Majdalani, J., "Biglobal Stability of Cylindrically-Shaped Hybrid and Solid Rockets with Injecting or Reactive Headwalls," AIAA 2012-3810, presented at 48th Annual AIAA/ASME/SAE/ASEE Joint Propulsion Conference, Atlanta, GA, July 29–August 1, 2012. Two Nominations for Best Paper in Internal Ballistics Modeling by Steven Frolik and Brain Evans.
5. **Elliott, Trevor S.**, "Theoretical Power Generation and Emissions, Experimental Validation, and Educational Application of an Internal Combustion Engine," M.S. Thesis, University of Tennessee at Chattanooga, December 2009. 186 Pages.

(d) Synergistic Activities

1. Current research advances hydrodynamic instability analysis through creation of new mathematical models and computational methods (biglobal analysis) in order to better understand combustion instabilities in solid and hybrid rockets.
2. Maintain various industrial partnerships to facilitate real world design projects assigned in the Interdisciplinary Design (two semester) course sequence were all engineering disciplines work together to create a fully developed prototype for the industrial partner.
3. Modified design course curriculum, including award of grant funds for hardware, to integrate 3D prototyping (3D Printing) into the course with reflective assignments to understand when the use of various additive manufacturing techniques are advantageous/unnecessary. Received "Beyond the Classroom" designation from the UT Chattanooga Experiential Learning Department.
4. Faculty Instructor for multiple STEM Workshops, most recently the 2017 Tennessee Higher Education Commission (THEC) Improving Teacher Quality Grant EXCEL – Exploring Clean Energy through hands-on Learning.
5. Serve as journal and textbook reviewer, steering committee member for advanced manufacturing committee in the greater Chattanooga area, member services for various professional societies, serve as Forum Deputy Technical Chair for the Propulsion & Energy Forum, Technical Area Organizer for the Hybrid Rockets Technical Committee, and Vice-Chair of the Solid Rockets Technical Committee within the American Institute of Aeronautics and Astronautics (AIAA). Lifetime member of ASME and ACM. Lifetime Senior Member of AIAA.

Gregory W. Heath, D.Sc., MPH

Guerry Professor
Department of Health and Human Performance
The University of Tennessee at Chattanooga
Phone: (423) 425-4432, Fax: (423) 425-4457
Email: Gregory-Heath@utc.edu

A. Professional Preparation

Westmont College	Santa Barbara, CA	Psychology	B.A.,	1972
Loma Linda University	Loma Linda, CA	Epidemiology	M.P.H.,	1977
Loma Linda University	Loma Linda, CA	Physiology/Nutrition	D.H.Sc.,	1977
Washington University	St. Louis, MO	Applied Physiology	NIH-Post-Doc,	1977-79
Centers for Disease Control (CDC)	Atlanta, GA	Epidemic Intelligence Service		1985-87

B. Appointments

2005–present **Professor and Assistant Vice Chancellor for Research**
University of Tennessee at Chattanooga, Dept. of Health and Human Performance, Chattanooga, TN, USA

2005–Present **Professor**
University of Tennessee College of Medicine Chattanooga, Dept. of Internal Medicine Chattanooga, TN, USA

2000–2005 **Lead Health Scientist**
Centers for Disease Control and Prevention, Division of Nutrition, Physical Activity, Obesity
Atlanta, GA, USA

1987–2000 **Epidemiologist/physiologist**
Centers for Disease Control and Prevention, National Center for Chronic Disease Prevention and Health Promotion
Atlanta, GA USA

1985-1987 **Epidemic Intelligence Service Officer (EISO),** Centers for Disease Control and Prevention, Center for Health Promotion and Education
Atlanta, GA

C. Products

Products Most Closely Related to Proposal

[1] **Heath GW**, Troped PJ. The role of the built environment in shaping the health behaviors of physical activity and healthy eating for cardiovascular health. Future Cardiology 2012; 8(5):677-9.

[2] **Heath GW**, Parra DC, Sarmiento OL, Andersen LB, Owen N, Goenka S, Montes F, Brownson RC. Evidence-based intervention in physical activity: lessons from around the world. Lancet 2012; 380:272-81.

[3] Sallis JF, Bull F, Guthold R, **Heath GW**, et al. Physical Activity 2016: Progress and Challenges: Progress in physical activity over the Olympic quadrennium. Lancet. 2016 Jul 27. pii: S0140-6736(16)30581-5. doi: 10.1016/S0140-6736(16)30581-5.

[4] **Heath GW**, Brownson RC, Kruger J, Miles R, Powell KE, Ramsey LT. The Effectiveness of Urban Design and Land Use and Transport Policies and Practices to Increase Physical Activity: A Systematic Review. Journal of Physical Activity and Health. 2006; 1:S55-S71.

[5] Bassett DR, Fitzhugh EC, **Heath GW**, et al. Estimated energy expenditures for school-based policies and active living. Am J Prev Med. 2013;44(2):108–113.

Other Significant Products

[1] Fulton JE, Carlson SA, Ainsworth BE, Berrigan D, Carlson C, Dorn JM, **Heath, GW**, et al. Strategic Priorities for Physical Activity Surveillance in the United States. *MSSE*. 2016; 48(10):2057-69.
[2] **Heath GW**, Kolade VO, Haynes JW. Exercise is Medicine™: A pilot study linking primary care with community physical activity support. Preventive Medicine Reports. 2015; 2:492-497.
[3] Lee IM, Bauman AE, Blair SN, **Heath GW**, Kohl HW 3rd, Pratt M, Hallal PC. Annual deaths attributable to physical inactivity: whither the missing 2 million? Lancet. 2013 Mar 23; 381(9871):992-3.
[4] **Heath GW**. The Role of the Public Health Sector in Promoting Physical Activity: National, State, and Local Applications. J Phys Act Health. 2009 Nov;6 Suppl 2:S159-67.
[5] **Heath GW**. Physical activity transitions and chronic disease. American Journal of Lifestyle Medicine. Jul 2009; vol. 3: pp. 27S - 31S.

Complete List of Published Work in MyBibliography:

[1] http://www.ncbi.nlm.nih.gov/sites/myncbi/1-5gXB6IwTxky/bibliography/47426538/public/?sort=date&direction=ascending

D. Synergistic Activities

Developed public health curricula with focus on active living research

In my first 2 years of appointment I developed graduate courses in introduction to epidemiologic methods; physical activity epidemiology; health behavior change; introduction to biostatistics; How Should We Live: A Quantitative Perspective.

Community Services

American Heart Association, Chattanooga Chapter Board of Directors (2007-2010)

Science Advisor: Grow Healthy Together Chattanooga, Chattanooga/Hamilton County Health Dept

Southside Community Health Coalition – Member (current)

Board of Trustees, Lifespring Community Health (clinic and health advocacy)

Professional Services

National:

- Chair, Science Board, President's Council on Fitness, Sports, and Nutrition – 2009-2012
- National Cancer Institute Participatory Research on Cancer Prevention – Advisory Committee
- Institute of Medicine (IOM) – Moderator for Physical Activity and Health Guidelines – 2006
- Journal of Physical Activity and Health – Editorial Review Board
- American College of Sports Medicine – Vice President (2008-present); Trustee (1996-1999)

Regional:

- Southeast Tennessee Regional Health Board Member (current)
- Governor's Council on Physical Fitness and Health – Member (2005-2010)

Awards

- Delta Omega, Kappa Chapter (Honorary Public Health Society)
- Charles C. Shepard Science Award, Prevention and Control (Centers for Disease Control and Prevention): "Cost Effectiveness of Community-based Physical Activity Interventions (2009).
- Elected to Alpha Society, University of Tennessee at Chattanooga Academic Honor Society (2006)

Farah Kandah

Department of Computer Science Engineering
University of Tennessee at Chattanooga
735 Vine Street
Chattanooga, TN 37405

a. Professional Preparation

- B. A. in Computer Science — The Hashemite University, Jordan, 2002
- M. S. in Computer Science — The University of Jordan, Jordan, 2005
- Ph. D. in Computer Science — North Dakota State University, Fargo, ND 2012

b. Appointments

- Assistant Professor, University of Tennessee at Chattanooga — Department of Computer Science and Engineering, Aug. 2012 – Present
- Teaching Assistant, North Dakota State University — Department of Computer Science, 2011 - 2012
- Research Assistant, North Dakota State University — Department of Computer Science, 2009 - 2011
- Lecturer and Course Coordinator, The Hashemite University — Department of Computer Science, 2005 - 2007
- Research Assistant, The University of Jordan — Department of Computer Science, 2003 - 2005

c.i. 5 Publications Most Closely related to the Proposed Project

1. Jacob Coleman, Farah Kandah, Steven Schmitt and Mohammed Akour: Community Trust Distribution in Vehicle Ad-hoc Networks, *New Trends in Information Technology (NTIT 2017).*
2. Farah Kandah, and Jesse Whitehead: Trust-based Survivability Provisioning in Wireless Mesh Networks, *International Journal of Information Processing and Management (IJIPM 2016).*
3. Oliver Nicolas, Farah Kandah, Li Yang: Efficient Key Management for Big Data Gathering in Dynamic Sensor Networks, *IEEE ICNC - Workshop on Computing, Networking and Communications (CNC). 2016*
4. Steven Schmitt, Farah Kandah: Android Permission Vulnerabilities and Awareness, *the 2016 fall ACM Mid-Southeast Conference. 2016*
5. Farah Kandah, and Adrain Powell: Ultimate Control and Security Over Data Localization in the Cloud, International Conference on Computing, Networking and Communications (ICNC 2015).

c.ii. 5 Other Significant Publications

1. Jesse Whitehead, Farah Kandah: Cluster-Based Dynamic Backup in Cognitive Radio Networks, *the IEEE ICNC - Workshop on Computing, Networking and Communications (CNC). 2016*
2. Farah Kandah, and Jesse Whitehead: Energy-aware Multipath Provisioning in Wireless Mesh Networks, *Consumer Communications and Networking Conference (CCNC 2015).*
3. Farah Kandah, Yashaswi Singh, Weiyi Zhang and Yulu Ma: Mitigating Misleading Routing Attack using Path Signature in Mobile Ad-Hoc Networks, *Global Communications Conference (GLOBECOM), 2013 IEEE*, pp.617-622, 2013.
4. Farah Kandah, Yashaswi Singh, and Weiyi Zhang: Mitigating Colluding Injected Attack using Monitoring Verification in Mobile Ad-hoc Networks, *Security and Communication Networks (SCN), Wiley*, 6, pp. 539-547, 2013. Farah Kandah, Yashaswi Singh, and Weiyi Zhang: Mitigating Eavesdropping Attack using Secure Key Management Scheme in Wireless Mesh Networks, *Journal of Communications*, 7, pp. 596-605, 2012.
5. Weiyi Zhang, Farah Kandah, Xiaojiang Du, and Chonggang Wang: Self-protecting Net- working

using Dynamic p-cycle Consideration with Link Capacity Constraint, *Security and Communication Networks, Wiley*, 2011.

d. Synergistic Activities (up to 5)

1. IEEE Member and IEEE Communication Society (ComSoc) member.
2. Served on Technical Program Committee for IEEE WCNC 2013 - 2016, IEEE ICC 2016, IEEE/ACM ICCVE 2012 - 2016, and IEEE Globecom 2010 - 2013.
3. Journal Reviewer: WILEY's Security and Communication Networks (SCN) Journal, International Journal of Information Processing and Management (IJIPM), Journal of Computer Systems, Networks and Communications (JCSNC).
4. Guest Editor: IEEE Comsoc Multimedia Communications Technical Committee (MMTC), Special Issue on Multimedia Communications in Future Wireless Networks (E-letter).
5. ChinaCom2012: Network and Information Security Symposium CO-Chair.

Joseph Kizza

PROFESSIONAL PREPARATION

Makerere University, Math-Computer Science, B.S. 1975
California State University, Sacramento, CA, Engineering (Computer Science), M.E. 1980
The University of Toledo, Toledo, OH, Mathematics, M.S. 1986
The University of Nebraska, Lincoln, NE, Computer Science, Ph.D. 1990

APPOINTMENTS

2009 – present	Professor and Head, Department of Computer Science and Engineering, University of Tennessee at Chattanooga, Chattanooga, TN
2002 – 2009	Professor and Director, UTC InfoSec Center, University of Tennessee at Chattanooga, Chattanooga, TN
1997 - 2002	Associate Professor, University of Tennessee at Chattanooga, Chattanooga, TN
1989 - 1997	Assistant Professor, University of Tennessee at Chattanooga, Chattanooga, TN
1995	Visiting Professor, University of East London, England

PROFESSIONAL PUBLICATIONS

J. M. Kizza. *Computer Network Security and Cyber Ethics* – 4th Edition - Hardcover,
J. M. Kizza. *Guide to Computer Network Security* – 2nd Edition – Hardcover,
J. M. Kizza. *Guide to Computer Network Security* – 1st Edition – Chinese.
J. M. Kizza. *Social and Ethical Issues in the Information Age* – 5th Edition - Hardcover,
J. M. Kizza. *Social and Ethical Issues in the Information Age* – 5th Edition - Archived Edition
J. M. Kizza. Africa's Indigenous Technologies Making Footprint on the World Stage, *International Journal of Computing and ICT Research* Vol. 7, Issue 1, pp 6-11, June 2013. http://www.ijcir.org/volume6-number1/
J. M. Kizza, Li Yang, "Social History of Computing and Online Social Communities", the *Encyclopedia of Social Network Analysis and Mining* (ESNAM), 2013.
J. M. Kizza, Li Yang, "Is the Cloud the Future of Computing?", *Security, Trust, and Regulatory Aspects of Cloud Computing in Business Environments*, 2013
J. M. Kizza. Investigating the Role of MOOCs in the African Educational and Development Objectives – A Synopsis, *International Journal of Computing and ICT Research* Vol. 7, Issue 2, pp 6- 8, December 2013. http://www.ijcir.org/volume6-number2/.
J. M. Kizza. Africa Can Greatly Benefit from Virtualization Technology – Part 1, *International Journal of Computing and ICT Research* Vol. 6, Issue 1, pp 6-10, June 2012. http://www.ijcir.org/volume6-number1/
J. M. Kizza. Africa Can Greatly Benefit from Virtualization Technology – Part II, *International Journal of Computing and ICT Research* Vol. 6, Issue 2, pp 6- 8, December 2012. http://www.ijcir.org/volume6-number2/.

COLLABORATION AND OTHER AFFLIATIONS

- Tennessee High Education Commission (THEC) Program Reviewer**,** Graduate programs in Computer Science
- ABET - Computer Science Accreditation Board (CSAB) Program Evaluator.
- Fulbright Review Board
- Editor –in-Chief for the International Journal of Computing and ICT Research (IJCIR)
- Member Editorial Board:
    - International Journal of Computing and ICT Research (IJCIR) – Editor-in-Chief
    - African Journal of Science, Technology, Innovation and Development.
    - International Journal of Emerging Mechanical Engineering Technology
    - The International Journal of Cyber Ethics in Education (IJCEE).
    - The African Journal of Information and Communication
    - African Journal of Science, Technology, Innovation, and Development.
    - International Cyber crimes Journal Society of Productivity Enhancements (ISPE)
    - International Journal of Information Science (IJIS)
    - The International Journal of Cyber Ethics in Education (IJCEE).

COLLABORATORS & OTHER AFFILIATIONS

Prof. Via Phoha, (Louisiana State University); Prof. Nasir Memon (Polytechnic School of Engineering, New York University); Prof. Ravi Nath, (Creighton University, Nebraska); Prof. Timothy Waema (University of Nairobi, Kenya); Prof. Mammo Muchie, (Tshwane University of Technology, South Africa). Dr. Li Yang (University of Tennessee-Chattanooga); Dr. Yu Liang (University of Tennessee-Chattanooga); Dr. Farah Kandah (University of Tennessee-Chattanooga); Dr. Mbaki Onyango (University of Tennessee-Chattanooga); Dr. Jennifer Ellis (University of Tennessee-Chattanooga).

(ii) Graduate Students supervised:

Dr. Margaret Nyambura Ndung'u – University of Nairobi;
Dr. Arthi R. Shankar, Visvesvaraya Technological University
Dr. Jayanthi K Murthy, Visvesvaraya Technological University
Dr. Julianne Susanne Sansa Otim, University of Groningen, The Netherlands.
Dr. S. Akhila, Visvesvaraya Technological University

Yu LIANG, PhD (Computer Science), PhD (Applied Mathematics)
Department of Computer Science and Engineering
University of Tennessee at Chattanooga
615 McCallie Ave., Chattanooga, TN 37403-2598
Tel: 423-425-4351, E-mail: yu-liang@utc.edu or hughliang@gmail.com

Dr. Yu Liang is currently working at the Department of Computer Science and Engineering of University of Tennessee at Chattanooga as an Associate Professor. His funded research projects cover the following areas: modeling and simulation, high-performance scientific and engineering computing, numerical linear algebra, the processing and analysis of large-scale sensory data, and computational mechanics. His research work has appeared in various prestigious journals, book and book chapters, and refereed conference, workshop, and symposium proceedings. Besides two NSF review panels, Dr. Liang is serving in the Journal of Mathematical Research and Applications (JMRA), Current Advances in Mathematics (CAM), and the International Journal of Security Technology for Smart Device (IJSTSD) as an editorial board member.

A. PROFESSIONAL PREPARATION

• Tsinghua University,	Computer Science	B.S., 1985-1990
• Beijing Polytechnic University	Computer Science	M.S., 1992-1995
• Chinese Academy of Sciences	Computer Science	Ph.D., 1998
• Univ. of Ulster	Applied Mathematics	Ph.D., 2005
• University of Minnesota	Computational Sci.	Postdoc., 2001-2005

B. APPOINTMENT

- 2013-now, Associate Professor / Computer Science**,** University of Tennessee at Chattanooga.
- 2010-2012, Summer Faculty Fellow **/** Sensor Application, the U.S. Air Force Research Lab.
- 2007-2013, Assistant Professor / Computer Science, Central State University.
- 2006-2007, Visiting Assistant Professor/Computer Science, Embry-Riddle Aeronautical Univ.

C. PUBLICATIONS:

(i) Five most closely related to proposal project

- **Y. Liang**, DL. Wu, D. Huston, G. R. Liu, Y. Li, CL. Gao, J. Ma, Chapter 12: Civil Infrastructure Serviceability Evaluation Based on Big Data, in "Guide to Big Data Application". Edited by S. Srinivasan. Springer Publishing.
- **Y. Liang,** D. Wu, G. Liu, Y. Li, L. Gao, and W. Wu, *Big Data-enabled Multiscale Serviceability Analysis about Aging Bridges*, Elsevier Digital Communications and Networks Journal. August 2016, 97-107. DOI: 10.1016/j.dcan.2016.05.002.
- **Y. Liang** and C. Wu, *A HADOOP-Enabled Sensor-Oriented Information System for Knowledge Discovery about Target-of-interest*, Internet of things - special issue of FUEE Scientific Journal (Impact Factor: 0.460), Vol. 29, No. 3, March 2016, 437-450.
- **Y. Liang,** M. Szularz and L. T. Yang, *Finite-element-wise Domain Decomposition Iterative Solvers Based on Polynomial Preconditioning*, DOI: 10.1016/j.mcm.2012.11.017, Mathematical and Computer Modeling (Impact Factor: 1.346). Vol. 58, Issues 1–2, July 2013, Pages 421-437.
- **Y. Liang**, and Z. Shi, *A Hessian-Free Newton-Raphson Method for the Configuration of Physics Systems Featured by Numerically Asymmetric Force Field*, Mathematical and Computer Simulation, (Impact Factor: 1.109), DOI: 10.1016/j.matcom.2016.11.011 (on press).

(ii) Five other significant publications

- **Y. Liang**, J. Weston and M. Szularz, *Generalized Least-squares Polynomial Preconditioners for Symmetric Indefinite Linear Equations*. Parallel computing (Impact Factor: 1.311), 28(2): 323-341 (2002).
- R. Mohan, Y. Purohit, **Y. Liang**, *Deformation Behavior of Nanoscale Material Systems with Applications to Tensile, Flexural and Crack Propagation*, Journal of Computational and Theoretical Nanoscience (Impact Factor: 0.911), Volume 9, Number 5, May 2012, pp. 649-661(13). **DOI:** 10.1166/jctn.2012.2075.
- J. Zhang, **Y. Liang** and Y. Zhang, *Atomic-level Protein Structure Refinement Using Fragment guided Molecular Dynamics Conformation Sampling*. Structure (Impact factor: 6.347), Vol.19, 1784–1795, December 2011.
- J. Zhang, **Y. Liang**, J.Z. Yan and J. Z. Lou, *Study of the molecular weight dependence of glass transition temperature for amorphous poly (L-lactide) by molecular dynamics simulation*, Polymers (Impact Factor: 3.438), Volume 48, Issue 16, 27 July 2007, 4900-4905.
- **Y. Liang**, S. Li, H. Zhang and C.D. Han, *Timing Sequence Testing for parallel Programs*, Journal of Computer Science and Technology (Impact factor: 0.678), 84-95. Jan. 2000.

D. SYNERGISTIC ACTIVITIES

- Program Committee Member, the 2017 IEEE International Conference on Smart City Innovations (August 4-8, 2017, San Francisco, USA, http://ieee-smartworld.org/2017/sci/).
- Review panelist for the 2015-2017 NSF Graduate Research Fellowship Program (GRFP).
- Editorial Board Member of the International Journal of Security Technology for Smart Device (IJSTSD, URL:http://www.sersc.org/journals/IJSTSD/), Journal of Mathematical Research and Applications (JMRA), and Current Advances in Mathematics (CAM).
- Member of Editorial Board and Program Committee Member, First International Workshop on Security Technology for Smart Device (STSD 2015), URL: http://interworkshop.org/STSD2015.
- Member of Editorial Board, Journal of Mathematical Research and Applications, URL: http://www.academicpub.org/jmra/ .
- Technique Program Committee member of the Embedded Computing and Systems Track, the 6th International Conference on Frontier of Computer Science and Technology (FCST 2011: http://trust.csu.edu.cn/conference/fcst2011/)
- Panel Expert for the Secondary Career-Technical Alignment Initiative (SCTAI), Ohio Board of Regents (2010-2013).
- Reviewer of "Sensor", "Supercomputing", "Journal of Applied Mathematics and Computer Science", "Journal of Parallel and Distributed Computing", and "Parallel Computing".

T. Daniel Loveless
Assistant Professor
Electrical Engineering Department
University of Tennessee at Chattanooga
Chattanooga, TN

a. Professional Preparation

Georgia Institute of Technology, Atlanta, GA, Electrical Engineering, B.S. 2004
Vanderbilt University, Nashville, TN, Electrical Engineering, M.S. 2007
Vanderbilt University, Nashville, TN, Electrical Engineering, Ph.D. 2009

b. Appointments

2014-present	Assistant Professor, Electrical Engineering Department, University of Tennessee at Chattanooga (UTC), Chattanooga, TN
2013-2014	Research Assistant Professor, Department of Electrical Engineering and Computer Science, Vanderbilt University, Nashville, TN
2011-2013	Adjunct Assistant Professor, Department of Electrical Engineering and Computer Science, Vanderbilt University, Nashville, TN
2009-2013	Senior Research Engineer, Institute for Space and Defense Electronics, Department of Electrical Engineering and Computer Science, Vanderbilt University, Nashville, TN
2009-2010	Instructor, Department of Electrical Engineering and Computer Science, Vanderbilt University, Nashville, TN

c. Products

Total number of publications: 82 (65 refereed articles/proceedings, 12 non-refereed proceedings, 2 theses, 3 book chapters)

Google Scholar **h-index of 17**; **i10-index of 31**; ≥ 909 total citations

Recent Publications (*Student Author)

1. **T. D. Loveless**, S. Jagannathan, E. X. Zhang, D. Fleetwood, J. Kauppila, L. W. Massengill, “Combined Effects of Total Ionizing Dose and Temperature on a K-band Quadrature LC-Tank VCO in a 32 nm CMOS SOI Technology,” *IEEE Trans. Nucl. Sci.*, vol. PP, no. 99, pp. 1-1, Jan. 2017.
2. *Y. P. Chen, **T. D. Loveless**, A. L. Sternberg, E. X. Zhang, J. S. Kauppila, B. L. Bhuva, W. T. Holman, M. L. Alles, R. A. Reed, R. D. Schrimpf, D. McMorrow, and L. W. Massengill, “Persistent Laser-Induced Leakage in a 20 nm Charge-Pump Phase-Locked Loop (PLL),” *IEEE Trans. Nucl. Sci.*, vol. PP, no. 99, pp. 1-1, Jan. 2017.
3. *Y. P. Chen, L. W. Massengill, B. L. Bhuva, W. T. Holman, **T. D. Loveless**, W. H. Robinson, N. J. Gaspard, and A. F. Witulski, “Single-Event Characterization of Bang-Bang All-Digital Phase-Locked Loops (ADPLLs),” vol. 62, no. 6, pp. 2650-2656, Dec. 2015.
4. <u>*K. J. Shetler</u>, N. M. Atkinson, W. T. Holman, J. S. Kauppila, **T. D. Loveless**, A. F. Witulski, B. L. Bhuva, E. X. Zhang, and L. W. Massengill, “Radiation Hardening of Voltage References Using Chopper Stabilization,” vol. 62, no. 6, pp. 3064-3071, Dec. 2015.
5. **Loveless, T. D.** and Holman, W. T. (2015). Single-Event Mitigation Techniques for Analog and Mixed-Signal Circuits. In. M. Bagatin & Gerardin (Eds.), *Ionizing Radiation Effects in Electronics: From Memories to Imagers* (Chp. 9).
6. J. S. Kauppila, L. W. Massengill, D. R. Ball, M. L. Alles, R. D. Schrimpf, **T. D. Loveless**, *J. Maharrey, *R. C. Quinn, J. D. Rowe, “Geometry-Aware Single-Event Enabled Compact Models for Sub-50 nm Partially Depleted Silicon-on-Insulator Technologies,” *IEEE Trans. Nucl. Sci.*, vol. 62, no. 4, pp. 1589-1598, Aug. 2015.

7. T. D. Haeffner, **T. D. Loveless**, E. X. Zhang, A. L. Sternberg, *S. Jagannathan, R. D. Schrimpf, J. S. Kauppila, M. L. Alles, D. M. Fleetwood, L. W. Massengill, and N. F. Haddad, "Irradiation and Temperature Effects for a 32 nm RF Silicon-on-Insulator CMOS Process," *IEEE Trans. Nucl. Sci.*, vol. 61, no. 6, pp. 3037-3042, Dec. 2014.
8. *Y. P. Chen, **T. D. Loveless**, *P. Maillard, *N. J. Gaspard, *S. Jagannathan, A. L. Sternberg, E. X. Zhang, A. F. Witulski, B. L. Bhuva, W. T. Holman, and L. W. Massengill, "Single-Event Transient Induced Harmonic Errors in Digitally Controlled Ring Oscillators," *IEEE Trans. Nucl. Sci.*, vol. 61, no. 6, pp. 3163-3170, Dec. 2014.
9. *N. N. Mahatme, *N. J. Gaspard, *T. Assis, *I. Chatterjee, **T. D. Loveless**, B. L. Bhuva, W. H. Robinson, L. W. Massengill, S.-J. Wen, R. Wong, "Kernel-Based Circuit Partition Approach to Mitigate Combinational Logic Soft Errors," *IEEE Trans. Nucl. Sci.*, vol. 61, no. 6, pp. 3274-3281, Dec. 2014.

Recent Conference Proceedings (*Student Author)

10. *INVITED* "Hardening-By-Design Techniques for Analog and Mixed-Signal ASICs," by T. D. Loveless, presented at the 12th International School on the Effects of Radiation on Embedded Systems for Space Applications (SERESSA), Montreal, Quebec, Canada, Nov. 2016.
11. *INVITED* "Radiation Effects and Basic Mitigation Techniques for Mixed-Signal Electronics," by T. D. Loveless, presented at the 2016 Hardened Electronics and Radiation Technology (HEART) Conference, Monterey, CA, Apr. 2016.
12. *INVITED* "Hardening-By-Design Techniques for Analog and Mixed-Signal ASICs," by T. D. Loveless, presented at the 11th International School on the Effects of Radiation on Embedded Systems for Space Applications (SERESSA), Puebla, Mexico, Dec. 2015.

d. Activities

1. Project mentor for nine 11th grade students from the STEM High School Fab Lab, "Mitigating Cold-Temperature Effects in High-Altitude Balloon Payloads," Oct.-Dec. 2016.
2. Panelist, The Baylor School Accelerator's Entrepreneurial Panel, "How to Develop an Idea," Nov. 2016.
3. "The Martian" and "UTChattSat: Engineering for Outer Space in the Classroom," Outreach Presentations at the Chattanooga Girls Leadership Academy, Chattanooga, TN, Apr. 19, 2016 and Oct. 6, 2016.
4. Recipient of 2016 GigTank365 Summer Fellowship (UTChattSat), *Co.Lab*, Chattanooga, TN, May-July 2016.
5. STEM Category Winner in Faculty Elevator Speech Competition, "Rocket Scientist, Engineer, Educator," *UTC's Research Dialogues*, Apr. 2016.
6. Outstanding Researcher Award, Electrical Engineering, University of Tennessee at Chattanooga, 2015-2016.
7. UTC General Education Steering Committee, Jan. 2017-present.
8. Awards committee, 2016 IEEE Nuclear and Space Radiation Effects Conference, May-Sept., 2016.
9. "Minimum Size and Maximum Packing Density of Nonredundant Semiconductor Devices," Baylor School Journal Club, Feb. 21, 2016.
10. Led the Electrical Engineering Department's efforts in 2015-2016 ABET re-accreditation cycle. Established college-wide methodology for student outcome assessment, Nov. 2015.
11. Community liaison for the College of Engineering and Computer Science (CECS) Electrical Engineering Department, Oct. 2015-present.
12. Member of the UTC Departmental Honors Committee, Sept. 2015-Aug. 2016.
13. Elevated to Senior Member, IEEE, June 2015.
14. Mentor for one East Ridge High School Senior project in electrical engineering, Jan.-May 2015.
15. Recipient of 3 best paper awards: GOMACTech 2012, IRPS 2011, GOMACTech 2010.
16. Recipient of the 2008 IEEE Nuclear Plasma and Sciences Society (NPSS) Graduate Scholarship Award for contributions to the fields of Nuclear and Plasma Sciences, March 2008.

James C. Newman III, PhD
Professor, Department Head of Mechanical Engineering
Email: James-Newman@utc.edu ; Phone: (423) 425-5489

Professional Preparation:

Old Dominion University	Norfolk, VA	Mechanical Engr.	B.S.	1993
Old Dominion University	Norfolk, VA	Aerospace Engr.	M.S.	1994
Virginia Tech	Blacksburg, VA	Mechanical Engr.	Ph.D.	1997

Appointments:

2015 – Present	Professor, Department of Mechanical Engineering, UTC
2014 – Present	Joint Faculty Appointment, Dept. of Energy, ORNL
2011 – 2015	Professor, Department of Computational Engineering, UTC
2002 – 2011	Associate Professor, Department of Aerospace Engineering, Miss. State U.
1997 – 2002	Assistant Professor, Department of Aerospace Engineering, Miss. State U.

Five Products Most Relevant to Proposal:

1. Anderson, W.K., Newman III, J.C., and Karman, S.L., "Stabilized Finite Elements in FUN3D," *Journal of Aircraft*, (2017), accessed August 28, 2017. doi: https://doi.org/10.2514/1.C034482
2. Anderson, W.K., Ahrabi, B.R., and Newman III, J.C., "Finite-Element Solutions for Turbulent Flow over the NACA 0012 Airfoil," *AIAA Journal*, Vol. 54, No. 9, Sept. 2016, pp. 2688-2704
3. Ahrabi, B.R., Anderson, W.K., and Newman III, J.C., "An Adjoint-Based hp -Adaptive Stabilized Finite-Element Method with Shock Capturing for Turbulent Flows," *Computer Methods in Applied Mechanics and Engineering*, Vol. 318, May 2017, pp. 1030-1065.
4. Zhang, X., Newman III, J.C., Lin, W., and Anderson, W.K., "Time-Dependent Adjoint Formulation for Metamaterial Optimization using Petrov-Galerkin Methods," *Applied Computational Electromagnetics Society Journal*, Vol. 1, No. 7, July 2016, pp. 201-214.
5. Behzadi, F., and Newman III, J.C., "A Semi-Discrete SUPG Method for Contaminant Transport in Shallow Water Models," *Procedia Computer Science*, Vol. 80, July 2016, pp. 1313-1323.

Five Other Signification Products:

1. Anderson, W.K., Newman III, J.C., and Karman, S.L., "Stabilized Finite Elements in FUN3D," *AIAA Science and Technology Forum and Exposition*, AIAA 2017-0077, Grapevine, TX, January 2017.
2. Lin, W., Newman III, J.C., and Anderson, W.K., "Design of Broadband Acoustic Cloak using Topology Optimization," Accepted for publication, *ASME International Mechanical Engineering Congress & Exposition*, IMECE Paper 2016-68135, Phoenix, AZ, Nov. 2016.
3. Ghasemi, A., Taylor, L.K., and Newman III, J.C., "An Embarrassingly Parallel Method for Curved Spectral/Finite Element Mesh Generation," *Proceedings of the ASME Fluids Engineering Division Summer Meeting*, FEDSM2016-7600, Washington, DC, July 2016.
4. Hasbestan, J.J., and Newman III, J.C., "Pleasingly Parallel Matrix Free Discontinuous Least Squares Spectral Element Algorithm for Fluid Flow with Nonconformal Element Refinement," *Proceedings of the ASME Fluids Engineering Division Summer Meeting*, FEDSM2016-7510, Washington, DC, July 2016.
5. Lin, W., Newman III, J.C., Anderson, W.K., and Zhang, X., "Shape Optimization of

Acoustic Metamaterials and Phononic Crystals with a Time-Dependent Adjoint Formulation: Extension to Three-Dimensions," *Proceedings of the 17th AIAA/ISSMO Multidisciplinary Analysis and Optimization Conference*, AIAA Paper 2016-3830, Washington, DC, June 2016.

Synergistic Activities:

1. Inducted as Associate Fellow in the American Institute of Aeronautics and Astronautics (AIAA). Class of 2017.
2. "Methods and Apparatus for an Asymmetrical Fairing," U.S. Patent No. 8,157,216. April 17, 2012.
3. Office of Naval Research Young Investigator Award Recipient. (2002 – 2005)

Donald R. Reising
Assistant Professor
Electrical Engineering Department
University of Tennessee at Chattanooga
Chattanooga, TN

a. Professional Preparation
University of Cincinnati, Cincinnati, OH, Electrical Engineering, B.S. 2006
Air Force Institute of Technology, Dayton, OH, Electrical Engineering, M.S. 2009
Air Force Institute of Technology, Dayton, OH, Electrical Engineering, Ph.D. 2012

b. Appointments

2014-present	Assistant Professor, Electrical Engineering Department, University of Tennessee at Chattanooga (UTC), Chattanooga, TN
2009-2014	Electronics Engineer, Air Force Research Laboratory - Sensors Directorate, U.S. Air Force, Dayton, OH
2012-2014	Adjunct Assistant Professor, Department of Electrical and Computer Engineering, Air Force Institute of Technology, Dayton, OH
2009-2012	Research Associate, Department of Electrical and Computer Engineering, Air Force Institute of Technology, Dayton, OH
2006-2009	Electronics Engineer, Aeronautical Systems Center, U.S. Air Force, Dayton, OH

c. Products

(i) 5 Most closely related to Proposed Project (*Student Author)

1. *Wheeler and Reising, "Assessment of the Impact of CFO on RF-DNA Fingerprint Classification Performance". IEEE Int'l Conference on Computing, Networking and Communications (ICNC), Jan. 2017.
2. Reising, Temple, and Jackson, "Discriminating Authorized and Rogue Devices in an OFDM-Based Network Using Dimensionally Reduced RF-DNA Fingerprints," IEEE Trans on Information Forensics and Security, Vol. 10, No. 6, pp. 1180-1192, Jun. 2015.
3. Reising, Prentice, and Temple, "An FPGA Implementation of Real-Time RF-DNA Fingerprinting for RFINT Applications." 2011 Military Communications Conference (MILCOM 2011), Oct. 2011.
4. *Reising, Temple, and Mendenhall, "Improving Intra-Cellular Security Using Air Monitoring with RF Fingerprints," IEEE Wireless Communication and Networking Conference (WCNC), Apr. 2010.
5. *Reising, Temple, and Mendenhall, "Improved Wireless Security for GMSK-based Devices Using RF Fingerprinting," Int'l J. Electronic Security and Digital Forensics, Vol. 3, No. 1, pp. 41-59, 2010.

(ii) 5 Other Significant Products (*Student Author)

1. *Harmer, *Reising, and Temple, "Classifier Performance Comparison Using 2D RF-DNA Features". IEEE Int'l Conference on Communications (ICC), Jun. 2013.
2. *Reising, and Temple, "WiMAX Mobile Subscriber Verification Using Gabor-Based RF-DNA Fingerprints," IEEE Int'l Conference on Communications (ICC), Jun. 2012.

3. *Reising, Temple, and Oxley, "Gabor-based RF-DNA Fingerprinting for Classifying 802.16e WiMAX Mobile Subscribers," IEEE Int'l Conference on Computing, Networking and Communications (ICNC), Jan. 2012.
4. *Williams, Temple, and Reising, "Augmenting Bit-Level Network Security Using Physical Layer RF-DNA Fingerprinting," IEEE Global Communications Conference (GLOBECOM), Dec. 2010.

d. Activities

1. Reviewer for the Institution of Engineering and Technology (IET) Communications Journal, IEEE Military Communications (MILCOM) Conference, IEEE Symposium on Wireless Technology and Applications, IEEE Global Communications Conference, IEEE Transactions on Information Forensics and Security, IEEE Journal on Selected Areas in Communications, IEEE Asia-Pacific Conference on Applied Electromagnetics, and International Journal on Security and Communication Networks.
2. Faculty volunteer for UTC's Read2Achieve program for incoming freshman, 2015-present.
3. Faculty advisor for the Electrical Engineering Department Senior Design Course, 2015-present.
4. Faculty lead and coordinator for UTC's College of Engineering and Computer Science MakerSpace, 2015-present.

Mina Sartipi, PhD

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A. Professional Preparation

Sharif University of Technology	Tehran, Iran	Electrical Engineering	B.Sc., 2000
Georgia Institute of Technology	Atlanta, GA	Electrical and Computer Eng.	M.S., 2003
Georgia Institute of Technology	Atlanta, GA	Electrical and Computer Eng.	Ph.D., 2006

B. Appointments

2017–present **Lead Scientist for Smart Cities and Urban Science and Technology**
University of Tennessee at Chattanooga,
Chattanooga, TN, USA

2015–present **Professor & PhD Program Coordinator**
University of Tennessee at Chattanooga, Dept. of Computer Science and Engineering,
Chattanooga, TN, USA

2016–2017 **Urban Science and Technology Program Leader**
SimCenter, University of Tennessee at Chattanooga,
Chattanooga, TN, USA

2011–2015 **Associate Professor**
University of Tennessee at Chattanooga, Dept. of Computer Science and Engineering
Chattanooga, TN, USA

2007–2011 **Assistant Professor**
University of Tennessee at Chattanooga, Dept. of Computer Science and Engineering
Chattanooga, TN, USA

2006–2007 **Assistant Professor**
University of Tennessee at Chattanooga, Dept. of Electrical Engineering
Chattanooga, TN, USA

C. Products

Products Most Closely Related to Proposal

[1] J. Cho, Z. Hu, N. Fell, G. Heath, R. Qayyum, and M. Sartipi, “Hospital Discharge Disposition of Stroke Patients in the State of Tennessee,” Journal of the Southern Medical Association, accepted, September 2017.

[2] B. Williams, B. Allen, Z. Hu, H. True, J. Cho, A. Harris, N. Fell, and M. Sartipi, "Real-Time Fall Risk Assessment Using Functional Reach Test," The International Journal of Telemedicine and Applications, January 2017.

[3] Z. Hu, S. Mohagheghi, and M. Sartipi, “Efficient Data Acquisition in Advanced Meter Infrastructure”, in Proc. of IEEE Power and Energy Society, July 2015.

[4] A. Harris, H. True, Z. Hu, J. Cho, N. Fell, and M. Sartipi, “Fall Recognition using Wearable Technologies and Machine Learning Algorithms,” in the Proc. of IEEE Big Data Conference, December 2016.

[5] Z. Hu, S. Mohagheghi, and M. Sartipi, “Flexible Data Acquisition, Compression, and Reconstruction in Advanced Metering Infrastructure,” in Proc. of Power Systems Conference, March 2016.

Other Significant Products

[1] J. Cho, Z. Hu, and M. Sartipi, “Post-stroke Discharge Disposition Prediction using Deep Learning,” in Proc. of IEEE SoutheastCon, March 2017.

[2] B. Williams, B. Allen, H. True, N. Fell, D. Levine, and M. Sartipi, “A Real-time, Mobile Timed Up and Go System”, in Proc. of IEEE Body Sensor Networks Conference, June 2015.

[3] B. Allen, R. Derveloy, N. Fell, W. Gasior, G. Yu, and M. Sartipi, “Telemedicine Assessment of Fall Risk Using Wireless Sensors,” in Proc. of IEEE International Conference on Sensor and Ad Hoc Communications and Networks, June 2014.

[4] L. Yang, M. Sartipi, M. McNeely, “Usable Protection to Healthcare Application”, in Proc. of ACM Workshop on Cyber Security and Information Intelligence Research, January 2011.

[5] F. Delgosha, M. Sartipi, and F. Fekri, “Construction of Two-dimensional Paraunitary Filter Banks over Fields of Characteristic Two and their Connections to Error-Control Coding,” IEEE Transactions on Circuits and Systems I, Volume 55, Issue 10, pp. 3095-53109, November 2008.

D. Synergistic Activities

- **IEEE Senior Member**
- **Founding Director**

  2012-present, Smart Communications and Analysis Lab
- **Mentoring of Young Women**

  As a female faculty member in the Computer Science and Engineering department, I encourage and advise undergraduate and graduate female students on research and possible careers in science.
- **Faculty Advisor for Computer Science Female Group**

  2016-present, Girls in Computer Science (GiCS)
- **Professional Services**
  - Presenter at multiple federal funding agency workshops
  - Keynote Speaker, Mid SouthEast ACM Conference
  - Planning member of the South Big Data Hub - Mobile Health
  - TPC member: Wireless / Radio Access Technologies VTC; International Workshop on Cyber-Physical System (CPS) and Its Computing and Networking Design at ICNC; IEEE GLOBECOM-Wireless Communications and Networking
  - Journal Reviewer: IEEE Transactions on Information Theory, IEEE Transactions on Communications, IEEE Communications Letters, IEEE Transactions on Signal Processing, EURASIP Journal on Wireless Communications and Networking
  - Conference Reviewer: IEEE INFOCOM, IEEE GLOBECOM, IEEE ISIT, IEEE ICC, IEEE SECON, IEEE ICASSP
- **Award**
  - UTC Outstanding Faculty Research and Creative Achievement award, 2016
  - “Keep the Stars Shining” Award, 2012
  - Outstanding Researcher in the College of Engineering and Computer Science, 2010, 2014, 2015
  - Outstanding Researcher in the Department of Computer Science and Engineering, 2010, 2013, 2015
  - Named UC Foundation Assistant Professor, 2008

Nurhidajat Sisworahardjo
Associate Professor
Electrical Engineering Department
University of Tennessee at Chattanooga
615 McCallie Avenue, Chattanooga, TN 37403-2598

Professional Preparation:
Institute of Technology Bandung, Bandung, Indonesia, Electrical Engineering, B.S. 1991
Illinois Institute of Technology, Chicago, IL, Electrical Engineering, M.S. 1998
The University of Alabama, Tuscaloosa, AL, Electrical Engineering, Ph.D. 2005

Appointments:

2017 – present	Associate Professor, Electrical Engineering Department, University of Tennessee at Chattanooga (UTC), Chattanooga, TN
2010 – 2017	Assistant Professor, Electrical Engineering Department, University of Tennessee at Chattanooga (UTC), Chattanooga, TN
2007 – 2009	Visiting Assistant Professor, Electrical and Computer Engineering department, University of South Alabama, Mobile, AL
2005 – 2007	Adjunct Assistant Professor, Electrical and Computer Engineering department, University of South Alabama, Mobile, AL
2005 – 2010	Research Associate, Electrical and Computer Engineering department, University of South Alabama, Mobile, AL

Five Products Most Relevant to Proposal:

1. S. K. Bunga, A. H. Eltom, N. Sisworahardjo, "Impact of Plug-In Electric Vehicle Battery Charging on a Distribution System," 2014 IEEE Industry Applications Society Annual Meeting, Vancouver, British Columbia, Canada, October 5 – 9, 2014.
2. A. Alharbi, A. H. Eltom, N. Sisworahardjo, "Impact of Plug-In Electric Vehicle Battery Charging on a Distribution System Based on Real-Time Digital Simulator," International Conference on Renewable Energies and Power Quality (ICREPQ'14), Cordoba, Spain, April 8 – 10, 2014.
3. N. Sisworahardjo, M. Y. El-Sharkh, "Validation of artificial neural network based model of microturbine power plant," 2013 IEEE Industry Applications Society Annual Meeting, Lake Buena Vista, FL, USA, October 6 – 11, 2013.
4. T. Yalcinoz, M. Y. El-Sharkh, N. S. Sisworahardjo, M. S. Alam, "Portable PEM Fuel Cell-Ultracapacitor System: Model and Experimental Verification," International Journal of Energy Research, Vol. 34, Issue 14, Pages: 1249 – 1256, November 2010.
5. N. S. Sisworahardjo, T. Yalcinoz, M. Y. El-Sharkh, M. S. Alam, "Neural Network Model of 100 W Portable PEM Fuel Cell and Experimental Verification." International Journal of Hydrogen Energy, Vol. 35, Issue 17, Pages: 9104 – 9109, September 2010.

Five Other Signification Products:

1. Akram Saad, N. Sisworahardjo, "Data Analytics-Based Anomaly Detection in Smart Distribution Network,"International Conference on High Voltage Engineering and Power System 2017 (ICHVEPS 2017), Bali, Indonesia, October 2 – 5, 2017.

2. A. Eltom, N. Sisworahardjo, E. McMahon, A. Ofoli, S. Craven, "A Comprehensive Approach to Power Sector Workforce Development," ASEE's 123rd Annual Conference & Exposition, New Orleans, LA, USA, June 26 – 29, 2016.
3. M. Y. El-Sharkh, N. S. Sisworahardjo, "Fuel Cell Applications in Distributed Generation," Book Chapter of Fuel Cell and Distributed Generation, ISBN: 978-81- 308-0179-7, F. J. Melguizo (editor), Research Signpost, India, 2007.
4. Sisworahardjo, N., Ofoli, A., Craven, S., Eltom, A. (2013). State-of-the-Art Laboratories for Training the Modern Power Workforce. IEEE Power & Energy Society General Meeting, Vancouver, British Columbia, Canada, July 21 – 25, 2013.
5. A. Eltom, N. Sisworahardjo, A. Ofoli, "The Evolution of UTC's Industry Grade Digital Relay Laboratory," Poster presented at Electric Energy Systems Curriculum for Sustainability Workshop, Napa, California, February 8 – 9, 2013.

Synergistic Activities:

1. Associate Editor of IEEE IAS Industrial Automation and Control Committee (IACC). 2012 – present.
2. Reviewer for International Journal of Hydrogen Energy, International Journal of Electrical Power and Energy Systems, Energy Economics, IEEE Transactions on Power Systems, IEEE/Power Engineering Society Letters, Electric Power Systems Research Journal, IEEE Transactions on Industry Applications/IEEE Industry Applications Magazine.
3. Member of Editorial Board of Journal of Asian Society of International Relations and Public Affairs (JASIRPA), ISSN: 1994-6640 and ISSN-Online: 1994-6659.
4. Organizing member of UTC Smart Grid Workshop 2012, Chattanooga, Tennessee.
5. Co-Chairman of the committee of 3rd Indonesia Focus 2011 Conference, Pittsburgh, PA.

KIDAMBI SREENIVAS
Associate Professor
Department of Mechanical Engineering
University of Tennessee at Chattanooga
Chattanooga, TN 37403

A. Professional Preparation:

Indian Institute of Technology, Madras, India	Aerospace Engineering	B.Tech.	1991
Mississippi State University	Aerospace Engineering	M.S.	1993
Mississippi State University	Engineering	Ph.D.	1996

B. Appointments:

2017 – Present	Associate Professor University of Tennessee at Chattanooga
2014 – Present	Joint Faculty Appointment Oak Ridge National Laboratory
2011 – Present	Research Professor University of Tennessee at Chattanooga
2002 – 2011	Associate Research Professor University of Tennessee at Chattanooga
2002 – 2002	Associate Research Professor Mississippi State University
1999 – 2002	Assistant Research Professor Mississippi State University
1998 - 1999	Visiting Researcher (Unstructured Grid Technology) Mississippi State University
1997 – 1998	Post-doctoral Fellow (Computational Fluid Dynamics) Mississippi State University
1991 – 1996	Graduate Research Assistant NSF ERC for Computational Field Simulation, Mississippi State University

C. 5 Publications Most Closely related to the Proposed Project:

1. Hereth, E., Sreenivas, K., Taylor, L.K., and Nichols, D.S., "An Automatic Parallel Octree Grid Generation Software with an Extensible Solver Framework and a Focus on Urban Simulation" AIAA Paper 2017-0587, Grapevine, TX, January 2017.
2. Sreenivas, K., Mittal, A., Hereth, L., Taylor, L.K., and Hilbert, C.B., "Numerical Simulation of the Interaction between Wind Turbines," Journal of Wind Engineering and Industrial Aerodynamics, Vol. 157, pp 145-157, October 2016.
3. Azarnoosh, J., Sreenivas, K., Arabshahi, A., "CFD Investigation of Human Tidal Breathing through Human Airway Geometry," Procedia Computer Science, Vol. 80, 2016, pp 965 - 976.
4. Mittal, A., Briley, W.R., Sreenivas, K., and Taylor, L.K., "A Parabolic Velocity-Decomposition Method for Wind Turbines," Journal of Computational Physics (accepted), available online 19

October, 2016.

5. Mittal, A., Sreenivas, K., Taylor, L.K., Hereth. L., and Hilbert, C.B., “Blade-Resolved Simulations of a Model Wind Turbine: Effect of Temporal Convergence,” Wind Energy, Vol. 19, Issue 10, pp 1761 – 1783, October 2016.

D. 5 Other Significant Publications:

1. Sreenivas, K., Mittal, A., Hereth, L., and Taylor, L.K., "Computational Simulation of the Interaction Between Tandem Wind Turbines with Offset," *AIAA Paper 2015-0224*, 33rd Wind Energy Symposium, AIAA SciTech 2015.

2. Gruetzemacher, R., Arabshahi, A., and Sreenivas, K., "Numerical Simulation of Airflow in a CT-based Human Airway Model with Physiologically Appropriate Boundary Conditions," Poster Presentation within the Respiratory Bioengineering Track, Biomedical Engineering Society Annual Meeting, San Antonio, Texas, October 2014.

3. Hyams, D.G., Sreenivas, K., Pankajakshan, R., Nichols, III, D.S., Briley, W.R., and Whitfield, D.L., “Computational simulation of model and full scale Class 8 trucks with drag reduction devices,” *Computers & Fluids*, Volume 41, Issue 1, February 2011, Pages 27-40.

4. Nichols, S., Sreenivas, K., Karman, S., and Mitchell, B., "Turbulence Modeling for Highly Separated Flows," *AIAA Paper 2007-1407*, 45th AIAA Aerospace Sciences Meeting and Exhibit, Reno, Nevada, Jan. 8-11, 2007.

5. Nichols, S., Mitchell, B., Sreenivas, K., Taylor, L., Whitfield D., and Briley, R., "Aerosol Propagation in an Urban Environment," *AIAA Paper 2006-3726*, June 2006.

E. Synergistic Activities (up to 5):

- SimCenter leadership role in unsteady viscous flow engineering applications, scientific computing, and unstructured grid technologies, including software development, integration, and management, and also facilitating teamwork to solve complex real-world engineering problems (University of Tennessee at Chattanooga)
- SimCenter leadership role in high-performance cluster computing, including cluster design, benchmarking, acquisition, and resource allocation (University of Tennessee at Chattanooga)
- Thesis Advisor for 2 Ph.D. students (University of Tennessee at Chattanooga)
- Committee Member for 3 Ph.D. students, and mentor for 1 Undergraduate Student Researcher (University of Tennessee at Chattanooga)

Craig R. Tanis

Professional Preparation

Tulane University	Computer Engineering / Robotics	BSE	1997
Tulane University	Computer Science	MS	1998
University of Tennessee	Computational Engineering	Ph.D.	2013

Appointments

- **2014-Present:** Assistant Professor, Faculty of Computer Science, University of Tennessee at Chattanooga
- **2010-2013:** Lecturer, Faculty of Computer Science, University of Tennessee at Chattanooga
- **2007-2010:** Graduate Student Researcher, SimCenter: National Center for Computational Engineering, University of Tennessee at Chattanooga
- **1999-2006**: Senior Programmer, Advance Internet, Jersey City, NJ
- **1996-1998**: Graduate Student Researcher, Mobile Robotics, Tulane University

Five Products Most Relevant to Proposal

1. R. Whalen, Y. Huang, C. Tanis, A. Sawant, B. Uzzi, and N. Contractor, "Citation Distance: Measuring Changes in Scientific Search Strategies," Proceedings of ACMWWW 2016, BigScholar.
2. W. K. Anderson, L. Wang, S. Kapadia, C. Tanis, and B. Hilbert, "Petrov-Galerkin and discontinuous-Galerkin methods for time-domain and frequency-domain electromagnetic simulations," Journal of Computational Physics, vol. 230, no. 23, pp. 8360–8385, Sep. 2011.
3. C. Tanis, "A NEW SOFTWARE FRAMEWORK FOR UNSTRUCTURED MESH REPRESENTATION AND MANIPULATION," University of Tennessee at Chattanooga, 2013.
4. C. Tanis, Splatter (2013-Present). Public git repository: `https://bitbucket.org/ctanis/splatt`.

Synergistic Activities

1. XSEDE Campus Champion for University of Tennessee at Chattanooga, 2014-Present
2. XSEDE Campus Champion Fellow 2015-16
3. Course developer for two graduate-level courses: (1) High-Performance Computing; (2) Parallel programming
4. Departmental "Teacher of the Year" 2011, 2012, 2013, 2014

Endong Wang, Ph.D., CPC, AIC, ASCE

Department of Engineering Management & Technology, EMCS 326B, University of Tennessee-Chattanooga, Chattanooga, TN 37403, Tel: 423-425-5778; Fax: 423-425-5818;
Email: Endong-Wang@utc.edu

Professional Preparation

Nanjing University of Science & Technology (Nanjing, China)	Structure Engineering	B.E.	2003
Southeast University (Nanjing, China)	Management Science	M.S.	2006
University of Nebraska-Lincoln (Lincoln, NE)	Construction	M.S.	2011
University of Nebraska-Lincoln (Lincoln, NE)	Engineering	Ph.D.	2013
University of Wisconsin-Milwaukee (Milwaukee, WI)	Sustainable Manufacturing	Postdoctoral	2013-2013

Appointments

2013−Present	Assistant Professor, Graduate Faculty, Construction Management, University of Tennessee-Chattanooga (UTC)
2013−2013	Postdoctoral Research Associate, Mechanical Engineering, University of Wisconsin-Milwaukee (UWM)
2009−2013	Graduate Research Assistant, Construction Management, University of Nebraska-Lincoln (UNL)
2008−2009	Adjunct Researcher, Key Laboratory of Contemporary Management Informatics
2006−2009	Instructor, Civil Engineering, Ocean University of China

Products

Five Products Most Closely Related to the Proposed Project

1. **Wang, E.**, Yuan, C. (2014). A hybrid life cycle assessment of atomic layer deposition process. <u>Journal of Cleaner Production</u>, 74, 145-154.
2. **Wang, E.**, Shen, Z. (2013). Lifecycle energy consumption prediction of residential buildings by incorporating longitudinal uncertainties. <u>Journal of Civil Engineering and Management</u>, 19, 161-171.
3. **Wang, E.**, Shen, Z. (2013). A hybrid Data Quality Indicator and statistical method for improving uncertainty analysis in LCA of complex system– application to the whole-building embodied energy analysis. <u>Journal of Cleaner Production</u>, 43,166-173.
4. **Wang, E.**, Shen, Z., Neal, J., Shi, J., Berryman, C., Schwer, A. (2012). An AHP-weighted aggregated data quality indicator (AWADQI) approach for estimating embodied energy of building materials. <u>International Journal of Life Cycle Assessment</u>, 17, 764-773.
5. Yuan, C., **Wang, E.**, Zhai, Q., Yang, F. (2015).Temporal discounting in life cycle assessment: A critical review and theoretical framework. <u>Environmental Impact Assessment Review</u>, 51, 23-31.

Five Other Significant Products

1. **Wang E** (2015). Benchmarking whole-building energy performance with multi-criteria Technique for Order Preference by Similarity to Ideal Solution using a selective objective-weighting approach. <u>Applied Energy</u>, 146: 92-103.

2. **Wang E**, Shen Z, Alp N, Barry N (2015). Benchmarking energy performance of residential buildings using two-stage multifactor data envelopment analysis with degree-day based simple-normalization approach. Energy Conversion and Management, 106: 530-542.
3. **Wang, E.**, Shen, Z., Grosskopf, K. (2014). Benchmarking energy performance of building envelopes through a selective residual-clustering approach using high dimensional dataset. Energy and Buildings, 75, 10-22.
4. **Wang, E.**, Shen, Z., Wang, L., Barry, N. (2014). Benchmarking building energy performance using Data Envelopment Analysis with normalized metrics---A residential case study. Computing in Civil and Building Engineering Conference, ASCE, Orlando, Florida.
5. **Wang, E.**, Shen, Z., Berryman, C. (2011). A building LCA case study using Autodesk Ecotect and BIM model. The 47th ASC Annual International Conference, Omaha, NE.

Synergistic Activities

1. *Professional Activities:*
   - Reviewer for 16 international journals and 15 conference proceedings, e.g., Energy 2015-2016; Energy and Buildings 2016; Journal of Cleaner Production, 2015-2016; Journal of Energy Conversion and Management, 2014-2016; International Journal of Life Cycle Assessment, 2014-2016; Building Simulation 2016; Big Data and Urban Informatics (Springer book) 2015; The 51st ASC Annual International Conference, 2015; LCA XIII conference, 2013
   - Technical committee member of 6 international conferences, e.g., the 11th Conference on Sustainable Development of Energy, Water and Environment Systems (SDEWES), Portugal, 2016; American Center for Life Cycle Assessment-LCAXVI conference, USA, 2016

2. *Major Awards and Registration:* Recipient of the Outstanding Researcher, CECS, 2014-2016; the 2013 Outstanding Graduate Student Award, UNL, 04/18/13; Certified Associate Constructor (AC), 12/20/13; Certified Professional Constructor (CPC), 04/05/14

3. *Related Projects:* Participated in three projects closely related to the proposed research "Advanced decentralized water/energy network design for sustainable infrastructure." USEPA, $1,249,995. 5/09-4/14; "Improving sustainability of atomic layer deposition: a hierarchical systems approach." NSF, $475,752. 07/12-12/14; "Energy Performance of Residential Building Using Simple-Normalization Based Two-Stage Data Envelopment Analysis." THEC-CEACSE, $91,000, 07/15-12/16; "A Systematic Investigation on Principal Energy Determinants of U.S. Residential Buildings", PREP Award, $14,036, 08/01/2016−07/31/2017; "Robust Building Energy Performance Evaluation through Multi-criteria Benchmarking Approach", Ruth S. Holmberg Grant, $3,000, 08/01/2016−12/31/2016; "EXCEL: EXploring Clean Energy through hands-on Learning", NSF, $ 1,192,081(Pending).

4. *Student Training:* Developed two undergraduate-level courses (UTC): Building Information Modeling, Green Building Rating Systems; and two graduate-level courses: Sustainability and LEED, Decision Making and Optimization (UTC) to strengthen sustainability education among undergraduates and graduates.

Robert S. Webster, Ph.D.

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Department of Mechanical Engineering
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Chattanooga, TN 37403

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fax: (423) 425-5229
Robert-Webster@utc.edu
http://www.utc.edu

Professional Preparation:

Auburn University	Auburn, AL	Aerospace Engineering	B.A.E 1986
Mississippi State University	Starkville, MS	Aerospace Engineering	M.S. 1994
Mississippi State University	Starkville, MS	Aerospace Engineering	Ph.D. 2001
Mississippi State University	Starkville, MS	Aerospace Engineering	2001-2002

Appointments:

Associate Professor, Department of Mechanical Engineering, University of Tennessee at Chattanooga, January, 2017 to Present
Associate Research Professor, Department of Computational Engineering, University of Tennessee at Chattanooga, July, 2008 to December, 2016
Assistant Research Professor, Department of Computational Engineering, University of Tennessee at Chattanooga, December, 2002 to July, 2008
Postdoctoral Fellow, Engineering Research Center, Mississippi State University, May, 2001 to December, 2002
Graduate Research Assistant (PhD Program), Engineering Research Center, Mississippi State University, August, 1994 to May, 2001
Graduate Research Assistant (MS Program), Engineering Research Center, Mississippi State University, January, 1992 to August, 1994
Aerospace Technologist, NASA Marshall Space Flight Center (MSFC), January, 1989 to December, 1991
Mechanical Engineer, US Army TMDE Support Group, Redstone Arsenal, AL, January, 1987 to December, 1988

Five Products Most Relevant to Proposal:

1.Collao, M. D., Webster, R. S., Sreenivas, K., and Lin, W., "Computational Study of the Effects of Protruding Studs Casing Treatment on the Performance of an Axial Transonic Turbofan," *AIAA-2016-4646*, 52nd AIAA/SAE/ASEE Joint Propulsion Conference, July, 2016.
2.Sreenivas, K, Webster, R. S., Hereth, E. A., Berdanier, R. A., and Key, N. L., "Computational Simulations of a Multi-stage Subsonic Research Compressor," *AIAA-2016-0395*, 54th AIAA Aerospace Sciences Meeting, January, 2016.
3.Webster, R. S., Sreenivas, K., and Hilbert, C. B., "Computational Simulation of the Fan and Low-pressure Compressor Stages of the Energy Efficient Engine," *AIAA-2015-1344*, 53rd AIAA Aerospace Sciences Meeting, January, 2015.
4.Lin, W., Sreenivas, K., Webster, R.S., and Hyams, D.G., "Effect of Casing Groove Locations on the Performance of an Axial Flow Stage," *AIAA-2013-3632*, 49th AIAA/ASME/SAE/ASEE Joint Propulsion Conference, July, 2013.
5.Webster, R. S., Sreenivas, K., Hyams, D. G., Hilbert, C. B., Briley, W. R., and Whitfield, D. L., "Demonstration of Sub-system Level Simulations: A Coupled Inlet and Turbofan Stage," *AIAA-2012-4282*, 48th AIAA/ASME/SAE/ASEE Joint Propulsion Conference, August, 2012.

Five Other Signification Products:

1. Hyams, D. G., Webster, R. S., Currier, N., and Sreenivas, K., “A Generalized, Interpolative Interface Method for Rotor-Stator Interactions,” *AIAA-2011-3700*, 20th AIAA Computational Fluid Dynamics Conference, June, 2011.
2. Webster, R. S., Sreenivas, K., and Hyams, D. G., “Unstructured Grid Technology Applied to Axial-flow Compressors,” *AIAA-2010-1605*, 48th AIAA Aerospace Sciences Meeting, January, 2010.
3. Chen, J-P, Johnson, B., Hathaway, M. D., and Webster, R. S., “Flow Characteristics of Tip-Injection on Compressor Rotating Instability via Time-Accurate Simulation”, *AIAA Journal of Propulsion and Power,* Vol. 25, No. 3, May-June, 2009, pp. 678-687.
4. Johnson, B. C., Webster, R. S., and Sreenivas, K., “A Numerical Investigation of S-Duct Flows with Boundary Layer Ingestion,” *AIAA-2010-0841*, 48th AIAA Aerospace Sciences Meeting, January, 2010.
5. Chen, J-P, Webster, R. S., Hathaway, M. D., Herrick, G. P., and Skoch, G. J., “Numerical Simulation of Stall and Stall Control in Axial and Radial Compressors,” *AIAA-2006-0418*, 44th AIAA Aerospace Sciences Meeting, January, 2006.

Synergistic Activities:

1.Reviewer for ASME TURBO EXPO: 2004 – 2005, 2009 – 2017
2.Reviewer for AIAA Joint Propulsion Conference: 2013 – 2017
3.Reviewer for AIAA Journal of Propulsion and Power: 2014 – 2015
4.AIAA Gas Turbine Engine Technical Committee; 2008 – 2015
5.AIAA Best Paper in Air Breathing Propulsion, 2005/2006; awarded by AIAA Air Breathing Propulsion Technical Committee for *AIAA-2006-0418* (co-author) entitled “Numerical Simulation of Stall and Stall Control in Axial and Radial Compressors”; awarded at 42nd AIAA/ASME/SAE/ASEE Joint Propulsion Conference Awards Luncheon, 12 July, 2006.

Dalei Wu, PhD

Assistant Professor
Department of Computer Science and Engineering
The University of Tennessee at Chattanooga
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Email: dalei-wu@utc.edu

A. Professional Preparation

Shandong University	Jinan, China	Electrical Engineering	B.Sc., 2001
Shandong University	Jinan, China	Electrical Engineering	M.S., 2004
Univ. of Nebraska-Lincoln	Lincoln, USA	Computer Engineering	Ph.D., 2010
Massachusetts Institute of Tech.	Cambridge, USA	Postdoc, Mechatronics	11/2011-06/2014

B. Appointments

2014–present **Assistant Professor**
University of Tennessee at Chattanooga, Dept. of Computer Science and Engineering, Chattanooga, TN, USA

2004–2005 **System Engineer**
ZTE Telecom Corporation, WiMAX R&D, Shenzhen, China

C. Selected Publications

Publications Most Closely Related to Proposal

[1] D. Wu, Q. Liu, H. Wang, D. Wu, and R. Wang, "Socially-Aware Energy-Efficient Mobile Edge Collaboration for Video Distribution," *IEEE Transactions on Multimedia*, vol. 19, no. 10, Oct. 2017.

[2] Y. Liang, D. Wu, G. Liu, Y. Li, C. Gao, Z. Ma, and W. Wu, "Big Data-enabled Multiscale Serviceability Analysis for Aging Bridges," *Digital Communications and Networks*, July 2016.

[3] J. Tian, H. Zhang, D. Wu, and D. Yuan, "Interference-Aware Cross-layer Design for Distributed Video Transmission in Wireless Networks," *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 26, no. 5, May 2015.

[4] D. Wu, D. Chatzigeorgiou, K. Youcef-Toumi, and R. Mansour, "Node Localization in Robotic Sensor Networks for Pipeline Inspection," *IEEE Transactions on Industrial Informatics*, vol. 12, no. 2, April, 2016.

[5] D. Wu, D. Chatzigeorgiou, K. Youcef-Toumi, S. Mekid, and R. Mansour, "Channel-Aware Relay Node Placement in Wireless Sensor Networks for Pipeline Inspection," *IEEE Transactions on Wireless Communications*, vol. 13, no. 7, July, 2013.

Other Significant Publications

[1] D. Wu, S. Ci, H. Luo, Y. Ye, and H. Wang "Video Surveillance over Wireless Sensor and Actuator Networks Using Active Cameras," *IEEE Transactions on Automatic Control*, vol. 56, no. 10, Oct. 2011.

[2] D. Wu, S. Ci, H. Wang, and A. Katsaggelos, "Application-Centric Routing for Video Streaming over Multi-hop Wireless Networks," *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 20, no. 12, Dec. 2010.

[3] D. Wu, S. Ci, H. Luo, and H.Guo, “A Theoretical Framework for Interaction Measure and Sensitivity Analysis in Cross-Layer Design,” *ACM Transactions on Modeling and Computer Simulation*, vol. 21, issue 1, Dec. 2010.
[4] D. Wu, S. Ci, H. Luo, H. Wang, and A. Katsaggelos, “A Quality-Driven Decision Engine for Service-Oriented Live Video Transmission,” *IEEE Wireless Communications*, vol. 16, issue 4, Aug. 2009.
[5] D. Wu, S. Ci, and H. Wang, “Cross-Layer Optimization for Video Summary Transmission over Wireless Networks,” *IEEE Journal on Selected Areas in Communications*, vol.25, no. 4, May 2007.

D. Synergistic Activities

- NSF “US Ignite: Collaborative Research: Focus Area 1: Fiber Network for Mapping, Monitoring and Managing Underground Urban Infrastructure,” $299,884, 01/01/2017 – 12/31/2019, PI. This project provides experiences for students in network-enabled sensing and using big data analytics and visualization to solve real-world problems and benefit city and community.
- Educational grants:
    - NSF “SFS Program: Strengthening the National Cyber Security Workforce,” $1,540,763, 01/01/2017 - 07/31/2021, Senior Personnel.
    - “Making Opportunities for Computer Science and Computer Engineering Students,” NSF, $585,020, 07/01/2013 - 06/31/2018, Co-PI.
- Development of course materials for courses CPSC 4240/5240 Principles of Data Analytics and CPSC 4530/5530 Data Visualization and Exploration at UTC.
- Editorial positions:
    - Editor-in-Chief, International Journal of Information Security and Privacy, since 05/2015.
    - Associate Editor, Wiley Security & Communication Networks, since 10/2011.
    - Co-director of the Communications – Frontiers Board, IEEE Multimedia Communications Technical Committee, since 10/2016.
    - Guest Editor, Wiley Security and Communication Networks Journal, Special Issue on Security and Networking for Cyber-physical Systems, 2012.
    - Guest Editor, Int'l. Journal of Ad Hoc and Ubiquitous Computing, Special Issue on Localization and Positioning for Healthcare Applications, 2013.
- Conference organization:
    - Technical Program Committee Co-Chair, the 10th EAI International Conference on Mobile Multimedia Communications, 07/ 2017.
    - Symposium Co-Chair, the Wireless Networking and Multimedia (WNM) Symposium for ICCC 2017.
    - Symposium Co-Chair, IEEE ICNC, Green Computing Symposium, 2013.
    - Track Co-Chair, BODYNETS, Special Track of Healthcare Applications and Challenges of Body Area Networks, 2013.
    - Workshops/Tutorials Chair, Mobimedia, 2015.
    - Member of Technical Program Committee, IEEE INFOCOM, 2016, 2017, 2018

Li Yang

Department of Computer Science Engineering
University of Tennessee at Chattanooga
735 Vine Street
Chattanooga, TN 37405

a. Professional Preparation

- B. A. in Finance — Jilin University, Changchun, Jilin, P. R. China , 1997
- M. A. in Finance — Jilin University, Changchun, Jilin, P. R. China, 2000
- M. S. in Computer Science — Florida International University, Miami, FL, 2003
- Ph. D. in Computer Science — Florida International University, Miami, FL, 2005

b. Appointments

- Director, University of Tennessee at Chattanooga — UTC InfoSec Center – a National CAE-IAE, Nov. 2011 – Present
- Professor, University of Tennessee at Chattanooga — Department of Computer Science and Engineering, Aug. 2014 – Present
- Associate Professor, University of Tennessee at Chattanooga — Department of Computer Science and Engineering, Aug. 2009 – 2014
- Graduate Coordinator, University of Tennessee at Chattanooga — Department of Computer Science and Engineering, Aug. 2008 – Present
- Assistant Professor, University of Tennessee at Chattanooga — Department of Computer Science and Engineering, Aug. 2005 – Aug. 2009
- Research and Teaching Assistant, Florida International University — Department of Computer Science, Jan. 2001 – Jul. 2005

c.i. 5 Publications Most Closely related to the Proposed Project

1. Xiaohong Yuan, Li Yang, Bilan Jones, Huiming Yu, Bei-Tseng Chu. Secure Software Engineering Education: Knowledge Area, Curriculum and Resources. Information Security Education Journal, (**2015**).
2. Prabir Bhattacharya, Li Yang, Minzhe Guo, Kai Qian, Ming Yang, Learning Mobile Security with Labware, Education column, IEEE Security and Privacy Magazine: Vol 12 No. 1, (**2014**).
3. Li Yang, Xiaohong Yuan and Dhaval Patel, Interactive Visualization Tools for Cross-Site Scripting and Cross-Site Request Forgery Attacks, International Journal of Information Technology and Computer Science (IJITCS), vol. 15, Issue 3, (**2014**).
4. Minzhe Guo, Prabir Bhattacharya, Ming Yang, Kai Qian, Li Yang, Learning Mobile Security with Android Security Labware, *Proceedings of the ACM Technical Symposium on Computer Science Education (SIGCSE)*, (**2013**).
5. Li Yang, Teaching Database Security and Auditing, *Proceedings of the 40th ACM Technical Symposium on Computer Science Education (SIGCSE)*, Chattanooga TN, (**2009**).

c.ii. 5 Other Significant Publications

1. Eric Reinsmidt, David Schwab, Li Yang, Securing a Connected Mobile System for Healthcare, the 17th IEEE High Assurance Systems Engineering Symposium (HASE 2016), Orlando, FL January, (**2016**).
2. Joseph Kizza, Li Yang, Is the Cloud the Future of Computing?, a book chapter in "Security, Trust, and Regulatory Aspects of Cloud Computing in Business Environments", (**2013**).
3. Wu He, Xiaohong Yuan, Li Yang, Supporting Case-based Learning in Information Security with Web-based Technology, *Journal of Information Systems Education (JISE) Special Issue: Global Information Security and Assurance*, accepted, (**2013**).

4. Li Yang, Managing Secure Database Systems, a book chapter in *Readings and cases in information security: law and ethics*, Whitman, M.E. & Mattord, H. J.,(editors), Course Technology, Cengage Learning, ISBN 1-435-44157-5, (**2011**).
5. Li Yang, Alma Cemerlic, Xiaohui Cui. A fine-grained reputation system for reliable routing in wireless ad hoc network, *Journal of Security and Communication Network*, (**2010**).

d. Synergistic Activities (up to 5)

1. Editor-in-chief of the International Journal of Information Security and Privacy (IJISP).
2. NSF S-STEM, Making Opportunities for Computer Science and Computer Engineering Students (MOCS) (with Joseph Kizza, Jack Thompson, Kathy Winters, Mina Sartipi), #1259873, PI, awarded, 2013-2018.
3. NSF Scholarship for Service (SFS), *Collaborative Project: Capacity Building in Mobile Security Through Curriculum and Faculty Development* (with Joseph Kizza, Kai Qian, Prabir Bhattacharya and Fan Wu), DUE-1241651, Lead-PI, awarded, $209,981, 2012-2015.
4. NSF-Scholarship for Service (SFS), *Collaborative Project: Developing Faculty Expertise in Information Assurance through Case Studies and Hands-on Experiences* (with Xiaohong Yuan in NC A&T SU and Bill Chu in UNC Charlotte), DUE-1129444, PI, awarded, $100,000, 2011-2013.
5. Collaborative Research Experience for Undergraduates (CREU): *Emerging Infectious Diseases: A Computational Multi-agent Model* (With Hong Qin in Spelman College), the Computing Research Association Committee on the Status of Women in Computing Research (CRA-W) in conjunction with the Coalition to Diversify Computing (CDC), $23,000 awarded, 2010 - 2011.

ACCOMPLISHMENTS & OUTCOMES

Project Overview

Provide a scientific / technical overview of your research project – hypothesis or scientific aims, methodologies and activities, outcomes, etc.

The study of anything related to hypersonic flows has always been a challenge, whether experimental measurements in tunnels or experimental measurements via flight testing, or computational simulation. The flow conditions (pressure, temperature, density, velocity) are so extreme, and the time scales on which things occur are so small that the accurate measurement and/or computation of these flows are not at all trivial. There are numerous physically complex phenomena that are simultaneously in play, and, ultimately, these phenomena have to be accounted for if a hypersonic vehicle, regardless of its purpose, is to be successful in its mission. That is to say, it is truly a multi-physics problem. This is significant with regard to computational simulations, because flow solvers have been evolving in the direction of having multi-physics capabilities. In other words, a given computational tool is expected to be able to simulate the fluid mechanics problem coupled with the thermal and solid mechanics problems of the vehicle. The primary goal of the research is to accurately and efficiently compute the aerothermodynamics and aerothermoelastics for hypersonic vehicles in support of Tennessee Aerospace Initiative. This is a computational effort to validate in-house flow solvers against experimental results on simple geometries that are similar in shape and size to critical areas on a hypersonic vehicle, such as the nose, wing leading edges, and inlet regions. This will lay the groundwork for further computational research in this area of the flight regime, which will be used in conjunction with recent and new experimental work to address the major concerns of hypersonic flight.

In order to demonstrate the performance, applicability, and accuracy of the *Tenasi* structured flow solver, the computations were performed for viscous hypersonic flow over four different geometries. A summary of the results for each configuration will be presented in the following;

- Blunt-Nosed Cylindrical Afterbody at various Mach number
  - Mach number from 1.5 to 15.0; shock stand-off distance agrees very well with theory
- Blunt-nosed Cones with Varying Half-angles (10 - 40 degrees) at a Mach number of 5.8, and Re = 2.38×10^5/in
  - Pressure distributions show excellent agreement with experiment
- Two Double-fins ($18^o \times 18^o$ and $23^o \times 23^o$) on Flat Plate show Shock interactions of Bodies in Close Proximity at a Mach number of 5.0, and Re = 1.52×10^5
  - Pressure distributions at various location show agree very well with experiment
- Blunted Cone-Flare Configuration at a Mach number of 6.0, and Re = 8.0×10^6/meter
  - Pressure distributions show excellent agreement with experiment
- Blunt-nosed Configurations are widely used in Hypersonic flow simulations
  - Strong shocks are produced, which tend to increase aerodynamic drag, but….
  - Strong shocks tend to reduce aerodynamic heating due in part to temperature reductions resulting from chemical reactions in vicinity of shock boundaries
  - For re-entry vehicles, the increased aerodynamic drag aids greatly in vehicle deceleration.

APPENDIX B

Awardee Project Reports

New Projects for FY2017

THEC

Center for Excellence in Applied Computational Science & Engineering

CUMULATIVE FINAL REPORT

(Submit as a Microsoft Word document [not PDF] via e-mail to Tony-Skjellum@utc.edu with a copy to Joanne-Romagni@utc.edu)

PROJECT OVERVIEW

Lead PI	*List personnel as you would like for them to appear in a formal report – e.g., Dr. John Smith / John Smith, PhD, etc.* Dr. Abdollah (Abi) Arabshahi
Co-PI(s)	Dr. Robert S. Webster
Other Personnel	*Identify by type – senior personnel, technicians, graduate students, undergraduate students* None
Project Title	Computational Simulations of the Aerothermal Environment of Hypersonic Flight Vehicles
Date Submitted	March 7, 2016
Award Start - End Date	July 1, 2016 – June 30, 2017
Non-Technical Summary – 500 words or less	Continued advances in physics-based simulation technologies in general, and in Computational Fluid Dynamic (CFD) in particular, are essential and required to support almost every aspect of the Hypersonic project. These capabilities will be used to generate accurate numerical predictions to provide and enhance our understanding of the complex flow phenomena that occur at the hypersonic regime (such as aerothermodynamics, aerodynamic, chemical reactions, and high heat transfer) around any flight vehicle. Current effort at the UTC/SimCenter is to develop and validate a physics-based numerical capability for simulating flow around hypersonic aerospace vehicles and components of vehicles, so that performance can be more accurately evaluated and better understood.
Project Web Page(s)	*Please provide the complete URL.*

Please attach a Quad Chart using the following format as an example:
http://www.usamraa.army.mil/pages/baa_paa/fy06quaddirections_jsto_baa.pdf.

List of Objectives / Aims / Major Milestones Proposed	Cumulative Outcomes / Accomplishments
In order to acquire the latest research progress in the aerothermodynamics of hypersonic vehicles, a comprehensive literature survey/review of hypersonic turbulent flow and available experimental data for vehicle flying at hypersonic speeds was conducted.	Acquired experimental data for the current in-house flow solver validation in the hypersonic regime.
A study of the shock detachment (stand-off) distance in hypersonic flow past blunt-nosed bodies. A numerical investigation was carried out on a circular blunt-nosed cylinder configuration at Mach number from 1.5 to 15.0.	Shock detachment distance compared with theory, and excellent and consistent agreement is achieved across this range of Mach numbers.
The object of the present study was to investigate computationally the surface pressure distribution and shock wave shape in the intermediate region extending from the stagnation-point zone on blunt nose to the end of a conical afterbody. Three models examined were spherically-blunted cones with half-cone angles of 10, 20 and 40 degrees. The nose bluntness varies between 0.40 and 0.80 times the base diameter at freestream Mach number of 5.8.	Series numerical investigations were performed on three truncated circular cones with tangentially connected spherical nose segments at a free-stream Mach number of 5.8. All the essential flow field features (shock shape and standoff distance) were well captured, and surface pressure compared well with the experimental data.
Another objective of this research was to assess in-house CFD capability for the prediction of shock wave turbulent boundary layer interactions at hypersonic velocities. Shock wave turbulent boundary layer interactions are a common feature occurrence in hypersonic flight with almost any flow deflection accompanied by shock formation. This part of research particularly is relevant and very important to the capabilities for providing a substantial knowledge and treatment of the complex issues in high-speed propulsion**.**	A detailed numerical investigation was carried out for very strong fully separated three-dimensional crossing shock-wave/turbulent boundary-layer interactions at Mach 5. The flowfield was generated by two sharp fins mounted at angle of attack on a flat plate in a manner closely resembling a portion of a scramjet inlet. Two symmetric double-fin configurations with deflection angles $\beta = 18\,°$ and 23° were considered. The computations for both symmetric double-fin configurations were validated by comparison with available experimental data. Furthermore, grid sensitivity study was performed for both symmetric double-fin configurations, until grid-solution independence was achieved. The current computational results exhibit good agreement with experimental data.
Implementation of the conjugate heat-transfer analysis technique for hypersonic applications was one of the most important themes of the present research proposal. The objective is an accurate prediction of temperature and heat flux	A comprehensive study of coupling of a heat-conduction model with an existing fluid dynamics solver was investigated. A simple conjugate heat transfer model was successfully implemented in the in-house Tenasi. The results confirm the reliability of the model in simulating a rectangular cavity filled with air, with two

distribution in space and time in a body and on its boundaries.	differently heated vertical walls and conductive horizontal boundaries.
The hypersonic flowfield around a blunted cone–flare exhibits some of the major features of the flows around space vehicles, e.g. a detached bow shock in the stagnation region and the oblique shock wave/boundary layer interaction at the cone–flare junction. The shock wave/boundary layer interaction can produce a region of separated flow. The region between the cone and the flare is particularly critical with respect to the evaluation of the surface heat flux. Indeed, flow separation is induced by the shock wave-boundary layer interaction, with subsequent flow reattachment, that can dramatically enhance the surface heat transfer. The exact determination of the extension of the recirculation zone is a particularly delicate task for the in-house Tenasi code. Indeed, apart from the modeling uncertainties associated to turbulence and real-gas effects, there are peculiar simulation difficulties associated to numerical issues such as the spatial accuracy of the numerical code and the computational mesh topology.	The computations for the seven grid levels were carried out and the results for the pressure coefficient were compared with experimental data. The grid sensitivity analysis has been performed until grid-solution independence was achieved. It clearly appeared that the solution was grid dependent especially in the recirculation area. Note that a coarse mesh was not capable of capturing the separation region in the cone-flare junction exactly. Refined mesh successfully predicted the surface pressure in all regions. The surface properties computed on the refined meshes did not appreciably vary from those computed on the corresponding coarser meshes, and it was safely assumed that the simulation results were grid independent. In general, the comparisons between computed and experiment was excellent. For example, the comparisons demonstrate that the size of the separated region and the magnitude of the pressure distributions through the separated and reattachment region were in excellent agreement with the experimental measurements.

Add rows as needed.

Challenges & Strategies Used to Address / Overcome:

Discuss any challenges or barriers that you encountered, particularly if you were impeded from achieving the objectives and milestones approved in your proposal.

No challenges or barriers arose that interfered with the proposal's approved objectives / milestones.

What didn't work? What did you disprove or learn from the parts that didn't meet your initial concept at the proposal?

Describe any areas where you did not meet goals; negative results are important too and should be explained and documented. Mostly, what did you learn besides what you achieved whether it met your expectations at the outset of this effort?

IMPACT & OUTCOMES

Impact on the career(s) of the PI, the co-PIs, and key collaborators	A positive career impact occurred for those involved in the proposal.
Students Impacted	*Please list students including name, brief description of how they were impacted, what degree sought or when graduated, and any other relevant details.*
Community and Broader Impacts	*Consider and discuss the technical and actual or potential societal impacts of your research project.* Recently, there has been renewed hypersonic interest in response to perceived near-peer threats. To enable the rapid collection of information and to address emerging threats, the U.S. Air Force plans to develop reusable vehicles. The current research will be to support the development and improvement of reusable hypersonic vehicle structure technology. This will increase national defense safety.
Work products reduced to practice; provide a bibliographical entry where appropriate	*Please include software, papers, presentations, posters, and creative works. Indicate Refereed Journal, Refereed Conference, Non-refereed Conference for each publication listed. For journal publications, indicate the impact factors where appropriate.* Arabshahi, A., Webster, S. R. and Sreenivas, K. "Computational Simulations of the Aerothermal Environment of Hypersonic Fight Vehicles," poster presentation within the UTC Research Day, April 12, 2017.

New inventions reduced to practice and when they will be formally disclosed;	*Please consider and include new software products that are subject to copyright but also methods and systems are potentially patentable. If you filed invention disclosures, patent or copyright applications during the period of performance, please indicate so here as well. If you wish to open source a software prototype data set, please state so; we will follow up with you with a disclosure process and guidance on how to proceed effectively for UTC and our research program, including required steps prior to doing so, and how properly to credit ownership to the UT system.*
Outreach & Collaboration	*Please list any visitors, workshops, or other collaborative events did you hold? Indicate the location (on campus, etc.).*

EXTERNAL FUNDING

Proposal Submissions	*Please list all sponsored program proposals submitted during the reporting period related to this or previous CEACSE awards.* Member of a joint proposal (Team members are; the University of Dayton Research Institute, University of Tennessee, and Purdue University) entitled “Reusable Hypersonic Vehicle Structures," to the Air Force Research Laboratory (AFRL). Enabling Technologies for High-speed Operable System (ETHOS) federal project BAA No. FA8650-17-S-2002. $ 10,000,000 / 3 years. August 2017.
Contracts / Awards Received	*List any awards or agreements received / executed related to this or previous CEACSE awards. Include sponsor name, sponsor program name (if applicable), project title, and award amount. If it is a non-funding agreement, identify by type (e.g., Data Use Agreement, Non Disclosure Agreement, Material Transfer Agreement, etc.).*
Sponsored Program Capacity Building Activities	*List all capacity-building activities in which you have engaged during the award period. Examples may include meeting with a sponsor program officer, attending an NSF/NIH/other sponsor regional workshop, participating in GWSW activities, attending on-campus workshops, etc.*

WHAT’S NEXT FOR THIS RESEARCH?

How will you follow up your CEACSE grant with work in the next 1,2, … 5 years?	
What other related research will you pursue (and with whom) in light of the support you’ve received from CEACSE?	
Tell us anything else we should know about this work not described above.	
What barriers (if any) do you face to reach these next goals?	

FINANCIAL ACCOUNTING

Financial Report:	**Total Award Amount:**	$97,859.00
	Cumulative Expenditures:	$92,465.30
	Remaining Award Amount:	$5,393.70

Please attach the following:

- *Final ledger report showing the final accounting for your award.*
- *Line item budget spreadsheet comparing your original, approved budget to how funds were actually expended.*
- *Updated budget narrative describing how funds were expended and how expense contributed to the achievement of project goals, objectives, and milestones.*

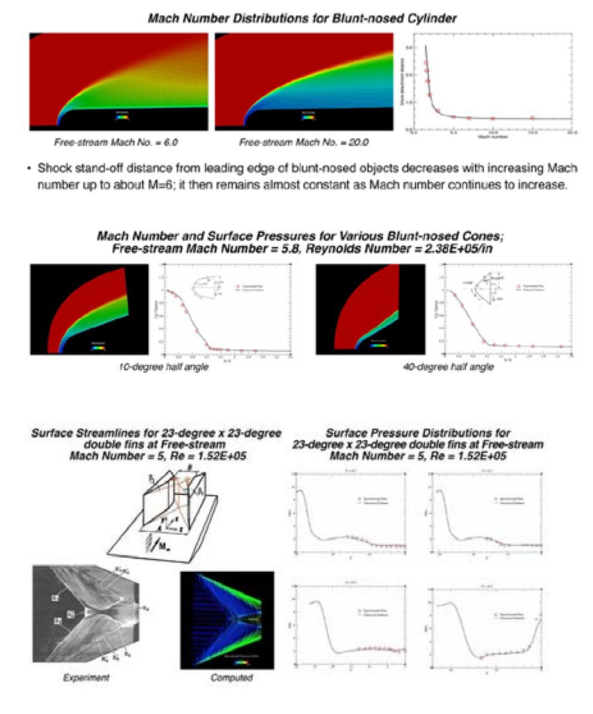
Supplemental Award Request	*Have you or do you anticipate applying for a supplemental award for any portion of the remaining balance? If so, please include the amount requested (or planned).*	$

UTC-SimCenter

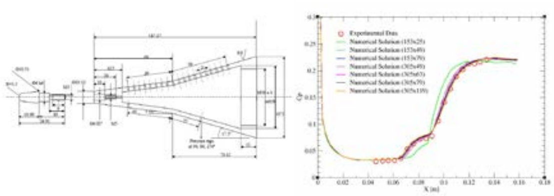
Technology Area of Interest: Hypersonic Airbreathing Vehicles Date: 8/30/2017

Proposal Title: Computational Simulations of the Aerothermal Environment of Hypersonic Flight Vehicles

Results



Surface pressure for a Blunted Cone-Flare Configuration at Free-stream Mach Number= 6.0, Re=8.0E+06



Operational Capability to be Provided:
Recently, there has been renewed hypersonic interest in response to perceived near-peer threats. To enable the rapid collection of information and to address emerging threats, the U.S. Air Force plans to develop reusable vehicles. The current research will be to support the development and improvement of reusable hypersonic vehicle structure technology. This will increase national defense safety.

Proposed Technical Approach: The primary goal of the research is to accurately and efficiently compute the unsteady aerothermodynamics and aerothermoelastics for hypersonic vehicles in support of Tennessee Aerospace Initiative.

Task 1: Conduct simulations of geometries that are representative of key components of hypersonic vehicles. These simulations will focus only on the aerodynamic aspects of the problem; the results will be compared to experimental data, if available, and/or previously published results from other flow

Budget and Schedule:

Total Budget:	$97,859.00
Actual Used:	$92,465.30
Balance:	$5,393.70

Total period of performance is 12 months;
Task 1 : Months 1-4
Task 2 : Months 3-6
Task 3 : Months 5-12
Task 4: Months 9-12

solvers. Task 2: Couple the surface heat transfer effects with the aerodynamics; compare the simulations with experimental results. Task 3. Add the capability for including aeroelastic effects; deflection and/or deformation as a result of aerothermal loading… that is the structural material response. Task 4: Results will be compared to experimental data, if available, and/or previously published results from other flow solvers.	Deliverables: Monthly Technical Report: Describing numerical methods, techniques and results that were developed or improved. Progress/Status Report: Final Report Organization Information: UTC-SimCenter, Dr. Abi Arabshahi 701 East M.L. King Boulevard, Chattanooga, TN 37403 Telephone: 423-425-5485 Email: abi-arabshahi@utc.edu

THEC
Center for Excellence in Applied Computational Science & Engineering

CUMULATIVE FINAL REPORT

(Submit as a Microsoft Word document [not PDF] via e-mail to Tony-Skjellum@utc.edu with a copy to Joanne-Romagni@utc.edu)

PROJECT OVERVIEW

Lead PI	Trevor S. Elliott
Co-PI(s)	(Originally Jan Evans)
Other Personnel	Chase Dobbins – Undergraduate student
Project Title	Investigation of Resources and Planning for Advanced Manufacturing Applications Center (AMAC) at UT Chattanooga
Date Submitted	June 28, 2016
Award Start - End Date	August 8, 2016 – June 30, 2017
Non-Technical Summary – 500 words or less	This work was centered on the development of a resource plan, personnel and infrastructural, related to creating a center for advanced manufacturing. To that end, faculty within the SimCenter, the college of engineering, and other colleges at UTC were linked to topic areas relevant to manufacturing. More specifically they were linked to areas found to be of interest to local manufactures and constituent base of UTC. While the manufacturer needs were assessed the center infrastructural requirements were analyzed. A major finding was that industries are not currently utilizing advanced techniques/technologies in their processes. These industries voiced a desire to test these new techniques and technologies within their current production and a need for integration with conventional processes. The subsequent research on integration yielded results about companies reacting to exactly this need, such as GF+ with a pallet system for moving products from conventional processes to advanced or additive processes in a bulk and automated fashion. This company indicated their process was in need of modeling and simulation similar to what the SimCenter could provide. In addition to the modeling and simulation needs this finding pointed out the possible need for a technology transfer component within the center. The facility layout produced within this work was a crucial element in space conversations and the space for the center has been secured. While creating the facility layout, equipment was assessed for its merits using a customized weighting scheme and desired equipment was selected for consideration. During the evaluation of potential equipment current faculty interests were considered

	which leads to a desired outcome of matched faculty interests to center subtopics and possible funding opportunities. The community impacts thus far have been in the area of awareness and soliciting of interested parties in the Chattanooga area. Entrepreneurial players such as CoLab, Branch Technologies, Collider Technologies, Feetz, and the Enterprise Center have been brought into the planning meetings for center realization. Industrial entities such as Komatsu, Tuftco, TN Rand, and Roper Company have been consulted to ascertain their needs and provide awareness about the center. Resources for certifications were located and resulted in an indirect student impact. These resources have now been implemented in a senior level course. The students in this course, all mechanical engineering students, will have the tools, training, and free access to certification for entry level lean six sigma certification.
Project Web Page(s)	No external website. Additional material being archived for this project for future reference.

Please attach a Quad Chart using the following format as an example:
http://www.usamraa.army.mil/pages/baa_paa/fy06quaddirections_jsto_baa.pdf.

ACCOMPLISHMENTS & OUTCOMES

Project Overview
This project was aimed at evaluating the potential pathways for the development of an advanced manufacturing center. This work includes details on center layout in terms of equipment and teaching/research resources as well as a business case for the center. The original direction was to evaluate local manufactures needs and match those to faculty expertise within the areas of Modeling and Simulation. After discussing desired outcomes with local manufactures, the desired direction for the center was found to be education, specifically certification(s) for various methodologies, concepts, and newly developed manufacturing equipment. This finding still lends itself to one of the initial deliverables, a framework for extramural funding in support of applied advanced manufacturing research, industrial collaboration, educational outreach, and workforce development.

List of Objectives / Aims / Major Milestones Proposed	Cumulative Outcomes / Accomplishments
Develop preliminary list of external funding sources with subtopics.	Outcome 1: Develop a program for workforce development supported by local Chattanooga area manufacturers and Chattanooga Chamber. Opportunities: Leverage past AMAC Steering Committee members already interested in similar outcome. Partnership with Chattanooga Chamber of Commerce and Chattanooga Regional Manufacturers Association. Leverage equipment manufacture contacts to obtain equipment matching for grant applications. Investments: FY2017 – Application to next LEAP Grant Competition (TN Labor Education Alignment Program) current years funding up to $1M for 30 months. Financial Goals: Consortium of industrial partners and projects to feed recurring costs of the program once established. Advancement of workforce development via NIST Manufacturing Extension Partnership (MEP) funding opportunity. Advancement in entrepreneurial efforts or business partnerships could be realized via NSF 16-555 SBIR/STTR. Outcome 2: Enhancements in nano manufacturing of nanowire anodes and battery manufacturing processes. Opportunities: Leverage current relationship with local and other battery manufacturers. Access to complete manufacturing processes currently in use and equipment essential to the research advancement effort. Investments: None Currently. Could seek internal CEACSE funds if FY2019 offering or external funding.

	Financial Goals: Extramural funding of $250k/y to support continued projects in advancing this area. Consideration of NSF PD-16-1788. Outcome 3: Design improvements of manufacturing equipment with emphasis in additive, laser etching, and nano manufacturing processes. Opportunities: Leverage current senior design projects involving redesign of existing processes and momentum with additive process currently under investigation. Access to small scale devices which can be used to create scalable concepts. Utilize current project with Aerojet contact for aerospace specific manufacturing equipment improvements. Investments: None Currently. Could seek internal CEACSE funds if FY2019 offering or external funding. Financial Goals: Extramural funding of $250k/y to support continued projects in advancing this area. Consideration of NSF PD-16-1468, Manufacturing Machines and Equipment (MME). Outcome 4: Development of network and autonomous algorithm controlled manufacturing devices and processes. Opportunities: Leverage senior design projects involving smart control and network remote control and data collection to aid this outcome. Leverage partnership with EPB and EPRI for hardware and existing protocols. Opportunity to work with US Ignite, tie into cyber security group, etc. Investments: None Currently. Could seek internal CEACSE funds if FY2018 offering or external funding. Financial Goals: Extramural funding of $150k/y to support continued projects in advancing this area. Consideration of NSF PD-16-018Y, Cybermanufacturing Systems.
Use subtopics determined from funding areas to create initial list of external (industrial) partners with sustainable interest.	Areas of indicated interest for training or development of new processes or procedures. Training: Robotics, specifically programing and optimization [Branch Technologies] IoT and smart manufacturing [TN Rand] IoT and Additive [Denso] Additive [Parkridge Medical Group]

<table>
<tr>
<td></td>
<td>Additive [McCallie School]
All groups in initial additive manufacturing questionnaire indicated interest in training for additive manufacturing. Further discussions revealed general interest in certifications in Additive, Lean, TPM, etc.
Additive interests were as follows:
<table>
<tr><td>Prototyping</td><td>Supply Chain Reduction</td><td>Custom/Complex Parts</td></tr>
<tr><td>Roper Corp</td><td>Roadtec Inc</td><td>Roadtec Inc</td></tr>
<tr><td>Parkridge Medical</td><td>Thornton Jewelry</td><td>Pilfrims Pride</td></tr>
<tr><td>TN Rand</td><td>McKee</td><td>TN Rand</td></tr>
<tr><td>Card-Monroe Corp</td><td>Card-Monroe Corp</td><td>Tuftco</td></tr>
<tr><td>Tuftco</td><td>Mohawk</td><td>Kirck Machine Shop</td></tr>
<tr><td>Kirck Machine Shop</td><td>Coca Cola Bottling</td><td>Mohawk</td></tr>
<tr><td>Komatsu</td><td>Mueller</td><td>Kock Foods</td></tr>
<tr><td>Hefferlin and Kronerberg</td><td></td><td>Komatsu</td></tr>
<tr><td>Alstom</td><td></td><td>Mohawk Industries</td></tr>
<tr><td>LJT Tubing Tennessee</td><td></td><td>LJT Tubing Tennessee</td></tr>
<tr><td>Siskin Steel Co</td><td></td><td></td></tr>
<tr><td>WNA Plastics</td><td></td><td></td></tr>
</table>
</td>
</tr>
<tr>
<td>Determine Faculty and Staff which are available and interested in subtopic areas.</td>
<td>Specifically to listed outcomes in funding and subtopic area:
For outcome 1: Faculty with backgrounds for this outcome are Alp, (L) Elliott, (T) Elliott, Evans, Margraves, Webster, Roundy [from school of business]
For outcome 2: Faculty with backgrounds for this outcome are (T) Elliott, Palchoudhury, Albu or Rybolt [chemistry department], Buiel [CEO of local battery manufacturing company].
For outcome 3: Faculty with backgrounds for this outcome are (L) Elliott, (T) Elliott, Evans, Margraves, Newman, Palchoudhury, Sreenivas.
For outcome 1: Faculty with backgrounds for this outcome are (T) Elliott, Evans, Reising, Sartipi, Sreenivas, Wigal, Yang.
Based from topic areas found within discussions
Prototyping: (L) Elliott, (T) Elliott, Evans, Goulet, Wigal
Supply Chain Reduction: Alp, McLean, Wigal
Custom/Complex parts: dependent on product and desired process.</td>
</tr>
<tr>
<td>Initial research on similar facilities in the area and standard</td>
<td>See supplemental Report on Center layout, equipment, costing, etc. Also, separate</td>
</tr>
</table>

market analysis and develop a business case including facilities layout, equipment, costing, possible deliverables, etc.	document on infrastructural requirements for equipment.

Add rows as needed.

Challenges & Strategies Used to Address / Overcome:

Discuss any challenges or barriers that you encountered, particularly if you were impeded from achieving the objectives and milestones approved in your proposal.

Key challenges were pin pointing industrial partner needs aligning with modeling and simulation with emphasis on SimCenter capabilities, issues with personnel availability, and meeting the change requests that were critical to layout and center design.

The modeling and simulation challenge was expected to some degree. From the outset, the PI desired to develop some pathways for meeting industry needs while enhancing the research portfolios of faculty within the university. The traditional model of advertising what faculty can do and then see if industry has a need didn't seem prudent for this type of applied center when initial conversations involved membership payment in support of the center. Instead the industry partners were asked about the problems they have generally and as might relate to specific technologies (such as additive devices). The result was finding topic areas that coincide with current faculty backgrounds.

There were a few scheduling issues with personnel. One was the result of teaching schedules for summer courses with the Co-PI. It was decided with medical issues and courses the load would be too great if the Co-PI stayed on this work. The second was the loss of the first planning summer month before the 2016 academic year. This shifted the ground work that was proposed for maximum utilization of student efforts during the academic year.

The last challenge was overcome via many meetings with those involved and several iterations on the site layout including ones that resulted from reduction in space allocation.

What didn't work? What did you disprove or learn from the parts that didn't meet your initial concept at the proposal?

Iterating on the layout and business case with the faculty of interest was a loftier goal than expected for this time period. Iterations were performed on the layout several times with administrative feedback/input but never with faculty that might be using the center. The center could be improved upon with more feedback from faculty.

IMPACT & OUTCOMES

Impact on the career(s) of the PI, the co-PIs, and key collaborators	The grant has widened the PI's view on funding possibilities as well as areas of interest for future research. The efforts on this work have resulted in the preparation of a national funding opportunity which is targeted for submission during the next cycle in 2018. Finally, the greatest impact for the PI was the realization that past Information and Technology experience should be capitalized on. Areas such as IoT are linked to technologies, protocols, and processes the PI is experienced with allowing for future contributions.
Students Impacted	Chase Dobbins – Mechanical Engineering Student – Graduated Fall of 2016. Expanded on his knowledge of dealing with vendors for technical and quote materials. Expanded on 2D/3D modeling experience by completing the last iteration of manufacturing space layout. Learned the detailing of a comprehensive business plan with competitive analysis and asset costing. Currently using experience to search for a position in advanced manufacturing or aerospace. All of the current and future ENME 4500 (or equivalent design course) While researching certifications of interest to industrial partners learned of free access to Lean Six Sigma White Belt certification test. Implemented course materials and certification this into the 4500 course for all ME students to graduate with this certification.
Community and Broader Impacts	This work includes workforce development which has the potential to make significant impacts on the Chattanooga and/or tristate area. With training programs the center would provide a means for access to new manufacturing equipment, processes, and technologies to which patrons might not otherwise have access. The center would be one of a select few centers of its kind if equipped as designed allowing for limitless new technology and research initiatives.
Work products reduced to practice; provide a bibliographical entry where appropriate	Internal documents for center logistics: Floor plans (original through revision 8) – final revision included "Advanced Manufacturing Facility Design" business, equipment justification, and costing report – Included Map of funding sources and potential faculty – within this report and past reports as well as emails with director Technical specification materials provided to administrators for building retrofit – Included.
New inventions reduced to practice and when they will be formally disclosed;	None

Outreach & Collaboration	There were no hosted events by UTC for this project. However, there were many correspondences with local industrial partners. Some of the discussions were developed while meeting the partners at their facilities and for detailed discussion of their processes and how UTC could work with them. Hosted meetings on UTCs campus were held with companies to discuss technologies and how UTC could develop new enhancements to these technologies (examples: hybrid additive processes, optimization of post processing using conventional methods in an automated system, and modeling/simulation/testing of algorithms for optimized material pooling in laser processes, etc). Meetings were held on campus with technical contacts at GF+, Eos, Hexagon, etc.

EXTERNAL FUNDING

Proposal Submissions	None
Contracts / Awards Received	Space within the Mapp Building on UTCs campus was provided for the establishment of this center. Currently approximate square footage is 6500 sqft. Used funding in current/pending funding reports for grants submitted during this period. One funded grant as Key personnel from THEC for workshop on improving teacher quality during this period. One grant pending review with this grant listed a current funding.
Sponsored Program Capacity Building Activities	Did not request enough funds for hosted workshop attendance. Located workshop materials from different national funding agencies and reviewed them for potential funding applications, such as NSF MME and Cyber Manufacturing. Also located and reviewed many workshop reports (MME, Materials Innovation, Advanced Manufacturing for Smart Goods, Nano Heat and Mass Transfer, Carbon Nano Materials, etc…)

WHAT'S NEXT FOR THIS RESEARCH?

How will you follow up your CEACSE grant with work in the next 1,2, … 5 years?	As a result of this research, a January or September 2018 submission to the NSF MME opportunity will be completed. We found a possible niche process/device which is not available in TN or any of its boarding states. This process fits SimCenter modeling and simulation interests on many levels including process optimization, device redesign, as well as custom product production. In the next year or two the space and infrastructural items will need final development and oversight. In the next one to five years I will serve on search committees to locate faculty with manufacturing backgrounds which are critical for the centers success.
What other related research will you pursue (and with whom) in light of the support you've received from CEACSE?	I have been working with a local battery manufacturer to utilize batteries in EV and ZEB applications but this work has resulted in interest in the battery and BMS design itself. To that end I currently have a senior design project involving optimized tab placement for high energy cells. Also in the battery area, I have interests in additive development (related to particle placement, density, and tracking). This interest could also be collaborative with a faculty member identified during the CEACSE work in Chemical Engineering and one in Chemistry.
Tell us anything else we should know about this work not described above.	
What barriers (if any) do you face to reach these next goals?	The primary barrier is time. With the ground work for proposal submission started the winter break should provide the time to complete and submit funding requests before the next semester.

FINANCIAL ACCOUNTING

Financial Report:	**Total Award Amount:**	$24,300.00
	Cumulative Expenditures:	$17,413.52
	Remaining Award Amount:	$ 6,886.48

Please attach the following:

- *Final ledger report showing the final accounting for your award.*
- *Line item budget spreadsheet comparing your original, approved budget to how funds were actually expended.*
- *Updated budget narrative describing how funds were expended and how expense contributed to the achievement of project goals, objectives, and milestones.*

Supplemental Award Request	*Have you or do you anticipate applying for a supplemental award for any portion of the remaining balance? If so, please include the amount requested (or planned).*	$0

THEC
Center for Excellence in Applied Computational Science & Engineering

CUMULATIVE FINAL REPORT

(Submit as a Microsoft Word document [not PDF] via e-mail to Tony-Skjellum@utc.edu with a copy to Joanne-Romagni@utc.edu)

PROJECT OVERVIEW

Lead PI	*List personnel as you would like for them to appear in a formal report – e.g., Dr. John Smith / John Smith, PhD, etc.* Gregory W. Heath, DHSc, MPH
Co-PI(s)	Mina Sartipi, PhD James Newman, PhD
Other Personnel	*Identify by type – senior personnel, technicians, graduate students, undergraduate students* Andrew Mindermann, BS – GIS Technician Guijing Wang, PhD – Health economist – CDC Eric Asboe, MPhil – Transportation Planner- City of Chattanooga
Project Title	Healthy and Intelligent Transportation Planning: Estimating Return on Investment Associated with Improved Infrastructure for Bicycling and Walking and Decreased Physical Inactivity in Chattanooga/Hamilton County
Date Submitted	September 1, 2017
Award Start - End Date	July 1, 2016 – June 30, 2017
Non-Technical Summary – 500 words or less	*Please provide a non-technical summary of your project that addresses the major objectives, accomplishments, and outcomes of your project. Discuss impacts of the project in terms of scholarly contributions to the field, scholarly outputs, student and community impacts, etc. Address how your project advanced or supported the mission of the SimCenter.* Based on data related to environment, transportation, and health, we proposed to provide a customized 'environmental infrastructure and health return-on-investment calculator' to be used by planners and personal users to guide in planning for pedestrian/bicycle path cost outlays for the former and healthy active wayfinding by the latter. Transport and recreation path/sidewalk costs were assessed in partnership with the city of Chattanooga's Department of Transportation for both recent and projected transport and recreation construction costs, land costs, projected construction time, and populations reached. Physical inactivity behavior associated impact on heart disease, stroke, type 2 diabetes, colon cancer, and breast cancer prevention outcomes were calculated using: 1) the relative

	risk (RR) for each of the chronic diseases in association with estimates of physical inactivity; 2) accessing through the Behavioral Risk Factor Surveillance System, the current prevalence of physical inactivity among the adult population 18 years and older residing in Chattanooga/Hamilton County and specifically Census Tracts 16, 18, 19, and 20; 3) using the results from steps 1 and 2 to calculate a Chattanooga/Hamilton County-specific and Census-specific Population Attributable Fraction (PAF) for each of the physical inactivity and chronic disease outcomes; and 4) Adjust the PAF's for each of the outcomes in accordance with the effect size expected from the sidewalks and paths on behavioral changes in terms of increased levels of physical activity among the adult population; and 5) adjusted cost of chronic disease's affected by changes in physical activity due to sidewalk/path changes. In addition, we created an application that provides a personalized planning for active transportation in response to vehicular traffic patterns and air quality so as to alert bike and pedestrian active transporters about the potential hazards and/or conditions of travel routes. Hence, in terms of urban planning, the data generated by our applications resulted in a potential tool that urban planners can use to maintain/build good/safe road/street networks and urban facilities to support active transportation and physical activities among residents. Our models assessing the impact of increased exposure to dedicated transport/recreation sidewalks/bike paths demonstrated a decrease in physical inactivity among adult residents in Chattanooga Census Tracts 16, 18, 19, 20 by a range of 25% to 50%, with a corresponding decrease in chronic diseases and their associated costs by as much as $1.2M over a project 4-year period, thus providing evidence for a return-on-investment for constructing such sidewalk/pathways.
Project Web Page(s)	*Please provide the complete URL.* NA

Please attach a Quad Chart using the following format as an example:
http://www.usamraa.army.mil/pages/baa_paa/fy06quaddirections_jsto_baa.pdf.

ACCOMPLISHMENTS & OUTCOMES

Project Overview

Provide a scientific / technical overview of your research project – hypothesis or scientific aims, methodologies and activities, outcomes, etc.

Introduction. Recent studies suggest that urban design, land use, and transportation planning at the community and street/neighborhood level contributes to enhanced transport options and increased physical activity among residents [1]. These changes have been linked to the prevention of premature mortality from the key non-communicable diseases (NCD) of coronary heart disease (CHD), type 2 diabetes (T2D), colon cancer (CCa), breast cancer among women (BrCa), stroke, and total mortality among residents as well [2]. However, there is a paucity of information about the return on investment (ROI) of active living infrastructure strategies with regard to the relative cost of the infrastructure and the yield in terms of increased levels of physical activity and the resultant cost savings due to the prevention of premature NCD morbidity and mortality and the associated indirect costs of such outcomes. [3]. In addition, since there often exists a latency between activity friendly infrastructural changes, there may be a period of transition, in which increased physical activity may be contra-indicated among persons with pre-existing health conditions, including those mentioned above, where certain periods of the day/season are potentially harmful and may synergistically result in an adverse outcome. For example, studies have shown negative outcomes for the interaction physical activity and environmental factors for asthma [4], myocardial infarction/coronary insufficiency [5] [6], and stroke [7]. Intelligent urban planning that incorporates the construction of urban recreational and transportation infrastructure (walking/biking) into public transportation systems has the potential to increase the regular physical activity and, consequently, impact the health outcomes of children/youth and adults at risk for the aforementioned health outcomes. Since such infrastructure changes are rare and costly, and very little is known about the temporal effects of such changes on transport behavior and physical activity, it is critical to assess the effects of these changes to better inform policy makers and urban planning experts.

The need for modeling in urban land-use and transportation planning was recognized in the early 1960s. Since then, these models have grown in complexity and scope, and they now incorporate data ranging from economic and demographic transitions, household and employment mobility, to real estate development and land pricing. Moreover, these models are tightly integrated with GIS. In these planning models, the computer modeling utilizes various pattern recognition and statistical inference methods based on available empirical data. However, the accessibility to computational resources that have become available over the past decade represents an opportunity to utilize significantly more data as well as advanced simulation technology for urban planning. This simulation technology permits enhanced predictive capability that otherwise would not be available. For example, the ability to accurately model pollutant and contaminant transport from fundamental sources, and to combine with this model the information now available from sensor data, health outcomes, cost, and their geographical incidence rates, creates a rigorous means of performing impact assessment to guide the development of future urban recreational and transport walking/biking infrastructure, decisions on industrial site location, and the evolution of public transportation systems.

Based on heterogeneous data related to environment, transportation, and health, we propose to provide a customized ‘environmental infrastructure and health ROI calculator’ to close the loop. This proposed calculator is intended to inform and guide community policy makers, urban planners, and transportation planners on prioritizing planning for the most cost-effective and cost-beneficial transport and recreational infrastructure enhancements in terms of yielding improved health outcomes for the citizens assigned to their responsibility.

It is known that physical inactivity is a major contributor to the steady rise in rates of T2D, CHD, stroke, and other NCDs in the United States [10]. Hence, health-oriented physical activities should be promoted. However, physical activities cannot always lead to health promotion. If there is no infrastructure or facilities available to support physical activities, there may be undue safety hazards associated with such activities. For example, people may view walking and bicycling as unsafe due to heavy traffic and/or due to a scarcity of urban infrastructure such as sidewalks, crosswalks, and bicycle lanes and dedicated paths [10]. The proposed calculator may provide a useful service to planners and policy makers that includes recommendations for health-enhancing active transportation using safe and activity-friendly routes.

Furthermore, considering existing health disparities, the calculator may provide environment-enabled health promoting options among people living in currently distressed neighborhoods in the Chattanooga region.

Methods. For the CEACSE urban planning project, we created an application/service that provides a personalized planning for active transportation. Active transportation, which involves physical activities, should be advocated for health promotion. Our application exploited two Python packages (i.e., OSMnx and NetworkX) for algorithm development and performance visualization. Data extracted from Open Street Map was used to generate the required road/street network/graph in our application. The personalized planning considers a series of objectives/constraints for each individual user. These objectives/constraints include (but not limited to) weather condition (e.g., temperature, sun exposure, and air pressure), road/street elevation/condition, and air quality. Precise elevation data was obtained through a Google elevation API. We can then compute elevation change and elevation grade for each edge in the network/graph. Figure 1 shows the elevation in the city of Chattanooga. Each node’s color is based on its elevation attribute, where yellow represents a higher elevation and purple represents a lower elevation. Figure 2 shows a zoomed in version of Figure 1. We also simulated air quality and labeled the corresponding data in the network/graph. Chattanooga is in the process of deploying air quality sensors. Our application can take real-time air quality data measured by these sensors. Meanwhile, by leveraging our previous research/achievement about mobile health/telemedicine, we can take into account the individual’s detailed/real-time health information simultaneously for health-enhancing active transportation. Different users may try different walkable routes based on their capabilities (e.g., health conditions) and needs. Figure 3 shows a route generated by a standard routing algorithm/shortest-path. As one can see the air quality was not part of the decision making. Figure 4 shows a route generated by our algorithm considering the length of the path as well as the air quality.

Transport and recreation infrastructure costs were assessed in partnership with the city of Chattanooga’s Department of Transportation for both recent and projected transport and recreation infrastructure construction costs, land costs, projected construction time, and populations reached. [3] Physical inactivity behavior associated impact on NCD prevention outcomes were calculated using: 1) the relative risk (RR) for each of the NCD outcomes of coronary in association with estimates of physical inactivity and controlling for all known confounders [3]; 2) accessing through the Behavioral Risk Factor Surveillance System, the current prevalence of physical inactivity and prevalence of those meeting current physical activity dose recommendations among the adult population 18 years and older residing in Chattanooga/Hamilton County and specifically Census Tracts 16, 18, 19, and 20 [11 and 12]; 3) using the results from steps 1 and 2 to calculate a Chattanooga/Hamilton County-specific and Census-specific Population Attributable Fraction (PAF) for each of the physical inactivity and NCD outcomes; and 4) Adjust the PAF's for each of the NCD outcomes in accordance with the effect size expected from the infrastructure changes in terms of increased levels of physical activity among the adult population; and 5) econometrically adjust the cost of NCD's affected by changes in physical inactivity due to environmental infrastructure changes. [13]

Results: The personalized active transport planning problem is a multi-objective multi-constraint optimization problem. We designed algorithms with the desired complexities by taking advantage of optimization theory and graph theory to get feasible solutions. In terms of urban planning, the data generated by this application can help urban planners to maintain/build good/safe road/street networks and urban infrastructures/facilities for active transportation and physical activities.

A demographic profile of Chattanooga/Hamilton County was generated using locally available vital statistics for the most recent inter-census estimates (Table 1). Estimate total population of the city/county is 340,973 persons. The proportion of the population that is white/Caucasian is ~75%; black/African-American, ~20%; Hispanic/Latino, ~5% (see Table 1). Eighty-six percent of residents have a high school or higher level of education, with 27.2% with a bachelor's degree or higher (Table 1). The NCD risk factors among adults 18 years and older in Chattanooga/Hamilton County identify 23% as current smokers; 66% as overweight or obese; 31% who are physically inactive; 35% with known hypertension; 35% with elevated blood cholesterol levels (Table 2). The leading causes of death among Chattanoogans is heart disease, cancers, and chronic obstructive lung disease (Table 3). Significant disparities exist for cause of death by race/ethnicity (Table 4) and gender (Table 5). The prevalence and estimated numbers of adults 18 years and older with coronary heart disease (7.2%); Stroke (3.8%); colon cancer (0.0032%); breast cancer among women (2.35%); and type 2 diabetes (12.6%) for a total of 67,255 adults with these conditions are listed in Table 6. The economic impact (direct and indirect costs) of these diseases projected through 2020 are per person are reported in Table 7. With the accumulated cost of these NCDs in Chattanooga projected to cost a total of $933M over the 3-year period or ~$311M per year (Table 8). Examining the impact of physical inactivity alone among the adult population on these NCD outcomes results in ~7.7% of coronary heart disease; 6.6% of stroke; 8.5% of colon cancer; 7.8% of breast cancer among women; and ~12% of all type 2 diabetes mellitus are a result of such inactive lifestyles (Table 9). Table 10 provides an estimation of the costs for each NCD outcome which is solely associated with physical inactivity for all adults with these conditions in Chattanooga/Hamilton County – these estimates project costs (direct and indirect) through the year 2020 at in excess of $93M. Tables 11 and 12 provide the cost estimates for the NCD outcomes in general and those associated with physical inactivity along for each of the Census Tracts (16, 18, 19, 20) most proximal to the existing and projected pedestrian and bicycle infrastructure. Table 13 provides the current estimates for physical inactivity among adults across these 4 census tracts – with a range of inactivity from 20.3% among adults living is Census Tract 18 to a high of 52% of adults who are inactive in Census Tracts 16 and 19. Using the effect size estimates for improved infrastructure from Heath et al. [1] these physical inactivity estimates are recalculated to demonstrate a projected decrease in physical inactivity due to the presence of active transport/recreation infrastructure of ~50% across all of the affected census tracts (Table 13). Finally, the current physical inactivity PAF's for each of the census tracts are calculated with estimated costs (direct and indirect) for each of the NCD outcomes as well as the recalculated PAF's based on the effect size differences due to exposure to existing the proposed pedestrian and bicycle infrastructure suggesting a decrease in physical inactivity related NCD costs for these Census Tracks dropping from an estimated cost of $2.7M to ~$1.5M (Table14). GIS generated maps demonstrate the changes in physical inactivity induced by enhanced access to pedestrian and bicycle infrastructure for Census Tracts 16, 18, 19, and 20 (Figures 5, 6, 7, and 8, respectively).

List of Objectives / Aims / Major Milestones Proposed	Cumulative Outcomes / Accomplishments
(1) Urban Environment Surveillance - This task consists of dynamic mass sensing and computational simulation and modeling.	We were able to access through sensor technology the air quality readings from onl EPA sensors, which are fixed ensors. Hence we were not able to assess air qualit to the proximal areas of the Tennessee River Park infrastructure and proposed bike/pedestrian spur into South Chattanooga (i.e., Alton Park)
(2) Transport and Recreation Infrastructure Cost Assessment – This task consists of costing out transport and recreation infrastructure construction costs, land costs, and projected construction time, and population reach.	Cost data for the Riverpark extension and the projected costs for the rail-to-trail s Alton Park were obtained through our collaborators at the City of Chattanooga's Transportation Department.
(3) Health Behavior Impact and NCD Prevention Outcomes and Cost Effectiveness - This task consists of: a.) calculating the relative risk (RR) for each of the NCD outcomes in association with physical inactivity and controlling for all known confounders; b.) accessing through the Behavioral Risk Factor Surveillance System, the current prevalence of physical inactivity and prevalence of those meeting current physical activity dose recommendations among the adult population 18 years and older residing in Chattanooga/Hamilton County; c.) using the results from steps 1 and 2 to calculate a	These data were accessed through the Behavioral Risk Factor Surveillance Data published by the Centers for Disease Control and Prevention (CDC), specifically census-level data on physical inactivity was obtained from the 500 Cities Project of CDC. Relative Risk for the selected chronic disease outcomes were derived from the work of Lee, et al. (Ref #3). Hamilton County-specific data were obtained through the Chattanooga/ Hamilton County Health Department's "Picture of Our Health, Hamilton County, Tennessee, 2015 Health Profile"

Chattanooga/Hamilton County-specific Population Attributable Fraction (PAF) for each of the physical inactivity and NCD outcomes;	http://health.hamiltontn.org/Portals/14/CommunityHealth/AssessmentPlanning/De%20of%20Our%20Health%202015%20Final.pdf
4) Adjust the PAF's for each of the NCD outcomes in accordance with the effect size expected from the infrastructure changes in terms of increased levels of physical activity among the adult population;	Applied effect sizes for the impact of bike and pedestrian infrastructure on physical activity from the systematic review by Heath et al., (Ref. #1)
5) econometrically adjust the cost of NCD's affected by changes in physical activity due to environmental infrastructure changes.	Utilized the online – 'Chronic Disease Cost Calculator' available through the CD https://www.cdc.gov/chronicdisease/calculator/index.html

Challenges & Strategies Used to Address / Overcome:

Discuss any challenges or barriers that you encountered, particularly if you were impeded from achieving the objectives and milestones approved in your proposal.

A primary challenge for the air quality monitoring/traffic patterning portion of our computational models, was that we were unable to deploy sensors in the specific vicinity of the TrailPark extension and proposed rail-to-trail spur. We were forced to use more generalized air quality data from the existing EPA fixed air quality sensors.

Due to a federally mandated travel and technical assistance moratorium imposed on CDC in January, 2017 – Dr. Wang, our collaborative health economist was not able to continue to work with our team. Hence, we deferred the econometric analyses portion of our project to the online cost calculators available through the CDC's website. Although not ideal, access to this calculator enabled us to project the costs of our selected chronic disease outcomes with some both an acceptable level of reliability and validity.

What didn't work? What did you disprove or learn from the parts that didn't meet your initial concept at the proposal?

Describe any areas where you did not meet goals; negative results are important too and should be explained and documented. Mostly, what did you learn besides what you achieved whether it met your expectations at the outset of this effort?

The Sensor monitoring goals were not met.

Also, we were unable to finalize our return-on-investment algorithm and subsequent Smartphone application.

IMPACT & OUTCOMES

Impact on the career(s) of the PI, the co-PIs, and key collaborators	Dr. Heath was further exposed to the use of econometric data and the direct and indirect costs of selected chronic disease outcomes Drs. Sartipi and Newman were further exposed to the use of public health data and health applications associated with their computational skillset. Mr. Mindermann was exposed and gained experience in mapping health-specific data using ESRI/GIS – where prior to this effort, his skills were mainly employed on environmental/ecology projects.
Students Impacted	*Please list students including name, brief description of how they were impacted, what degree sought or when graduated, and any other relevant details.* Graduate Students in Computer Science and Engineering were exposed to the modeling of environmental (air quality) data
Community and Broader Impacts	*Consider and discuss the technical and actual or potential societal impacts of your research project.* The collaboration with Chattanooga's Department of Transportation has opened up new opportunities to pursue the concepts of a healthy community and projects dedicated to environmental justice.

Work products reduced to practice; provide a bibliographical entry where appropriate	*Please include software, papers, presentations, posters, and creative works. Indicate Refereed Journal, Refereed Conference, Non-refereed Conference for each publication listed. For journal publications, indicate the impact factors where appropriate.* Presentations: Smart and Healthy Urban Planning – Oral presentation at the UTC Research Dialogues – April, 2017
New inventions reduced to practice and when they will be formally disclosed;	*Please consider and include new software products that are subject to copyright but also methods and systems are potentially patentable. If you filed invention disclosures, patent or copyright applications during the period of performance, please indicate so here as well. If you wish to open source a software prototype data set, please state so; we will follow up with you with a disclosure process and guidance on how to proceed effectively for UTC and our research program, including required steps prior to doing so, and how properly to credit ownership to the UT system.*
Outreach & Collaboration	*Please list any visitors, workshops, or other collaborative events did you hold? Indicate the location (on campus, etc.).* Physical Activity and Public Health Workshop – May 5, 2017 – PI assisted by other UTC faculty presented a workshop for professional staff of the Tennessee Department of Health Southeast Regional Office. Results from the current project were presented as examples on how public health data can be used to support the promotion of health and concept of a health community

EXTERNAL FUNDING

Proposal Submissions	*Please list all sponsored program proposals submitted during the reporting period related to this or previous CEACSE awards.* None

Contracts / Awards Received	*List any awards or agreements received / executed related to this or previous CEACSE awards. Include sponsor name, sponsor program name (if applicable), project title, and award amount. If it is a non-funding agreement, identify by type (e.g., Data Use Agreement, Non Disclosure Agreement, Material Transfer Agreement, etc.).*
Sponsored Program Capacity Building Activities	*List all capacity-building activities in which you have engaged during the award period. Examples may include meeting with a sponsor program officer, attending an NSF/NIH/other sponsor regional workshop, participating in GWSW activities, attending on-campus workshops, etc.* Submission of a symposium proposal for the Annual Meeting of the Southeast Chapter of the American College of Sports Medicine "Potential Impact of the Built Environment on Physical Activity and Chronic Disease Prevent in Communities"

WHAT'S NEXT FOR THIS RESEARCH?

How will you follow up your CEACSE grant with work in the next 1,2, … 5 years?	Finalize the ROI algorithm and smartphone application. Seek to test this app with data from other communities where infrastructure has or will be constructed for bike and pedestrian transport and recreational use. Apply these results into a larger effort to explore the concepts and principles of a 'Culture of Health' and Healthy Community
What other related research will you pursue (and with whom) in light of the support you've received from CEACSE?	Further exploration of 'natural experiments' where bike and pedestrian infrastructure is being built and/or proposed and actually measure physical activity levels of specific populations prior to, during, and following the construction of such infrastructure along with community-wide campaigns to promote such active transport and recreational infrastructure.
Tell us anything else we should know about this work not described above.	

What barriers (if any) do you face to reach these next goals?	Primary barriers are associated with procuring funding through NIH, CDC, or DOT –where the competition for active living research is quite vigorous. Another local barrier is the political resistance to further implement bike and pedestrian infrastructure outside of the immediate downtown Chattanooga area

FINANCIAL ACCOUNTING

Financial Report:	**Total Award Amount:**	$97,942
	Cumulative Expenditures:	$97,942
	Remaining Award Amount:	$0

Please attach the following:

- *Final ledger report showing the final accounting for your award.*
- *Line item budget spreadsheet comparing your original, approved budget to how funds were actually expended.*
- *Updated budget narrative describing how funds were expended and how expense contributed to the achievement of project goals, objectives, and milestones.*

Supplemental Award Request	*Have you or do you anticipate applying for a supplemental award for any portion of the remaining balance? If so, please include the amount requested (or planned).* NO, NA	$

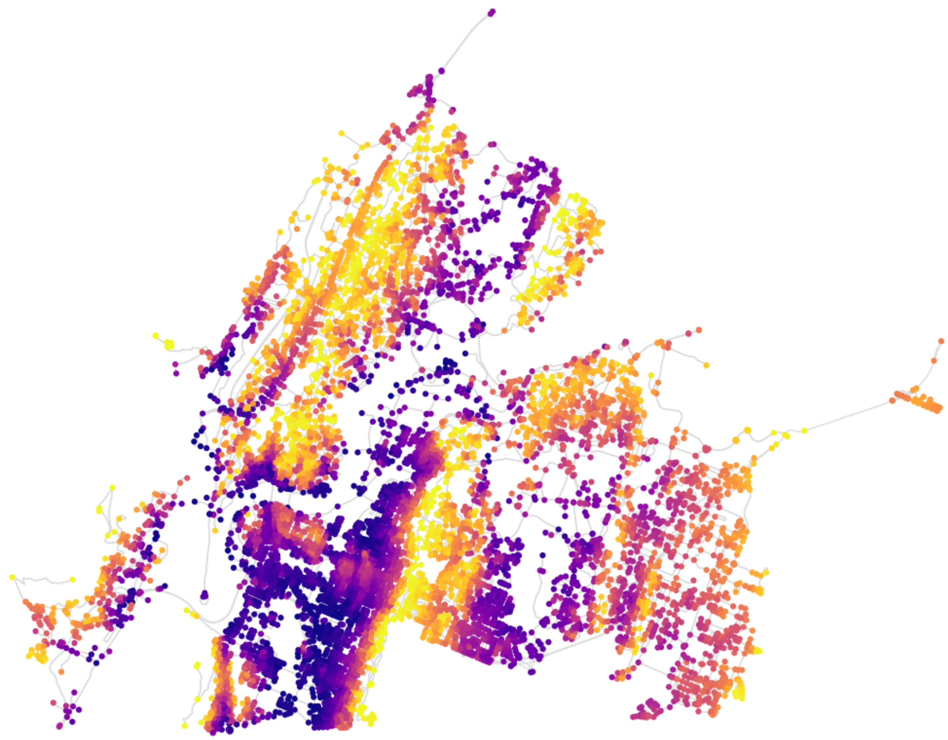


Fig. 1 – Chattanooga-Wide Elevation Map

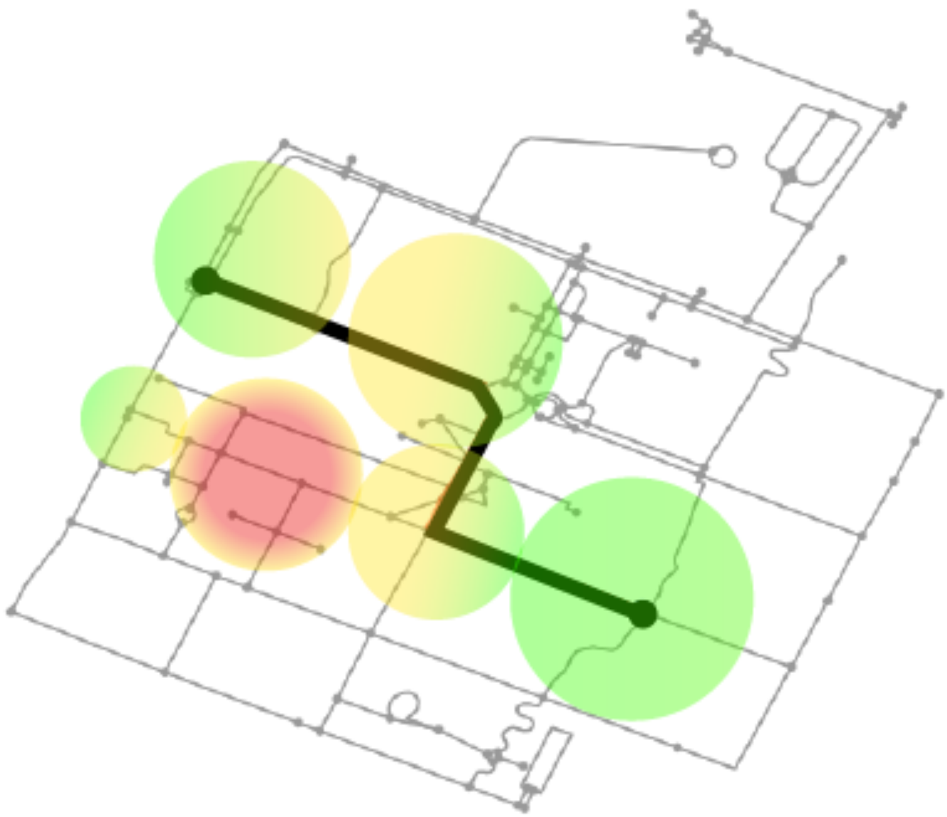


Figure 4 – A result of our proposed routing algorithm considering distance and air quality decision-making factors

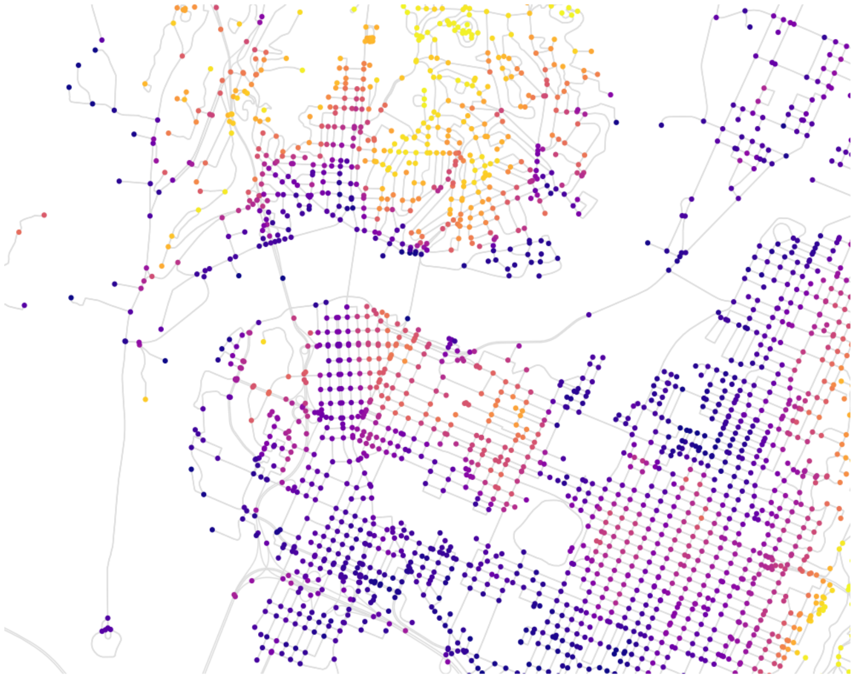


Fig. 2 – Zoomed in version of Chattanooga Wide Elevation

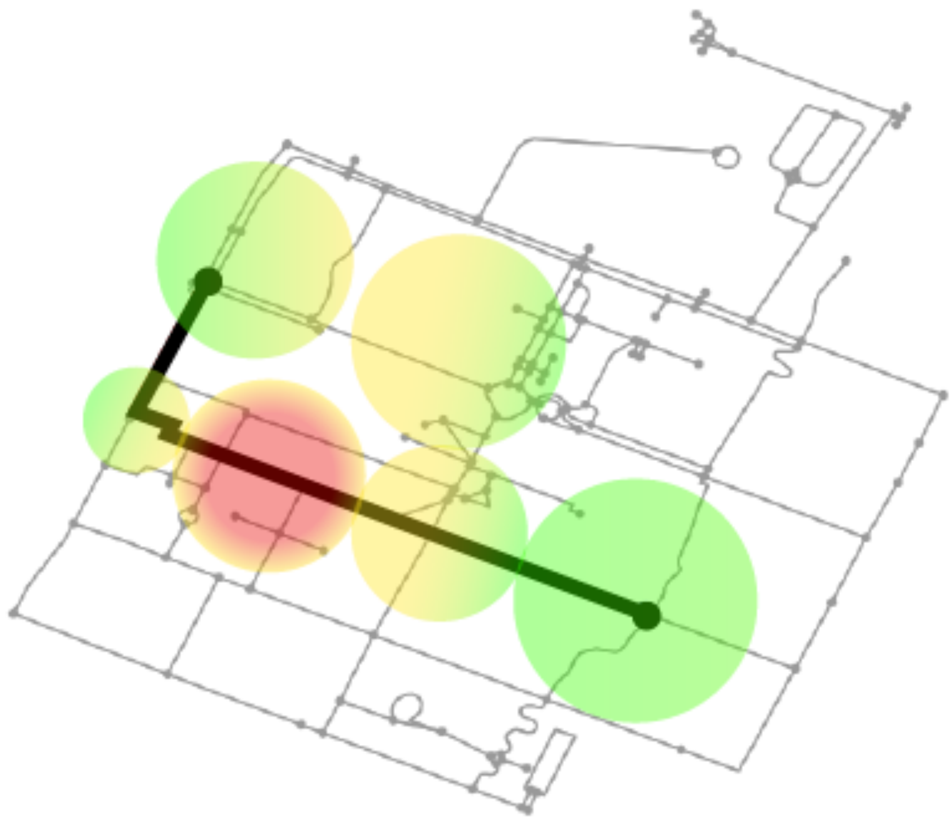


Figure 3 – A result of a routing algorithm considering only distance as a decision making factor

Table 1. Demographic Profile

	Hamilton County 2000	Hamilton County 2009-2013	Tennessee 2009-2013	United States 2009-2013
Population	307,896	340,973	6,402,387	311,536,594
Population under 5 years	6.0%	6.0%	6.3%	6.4%
Population under 18 years	23.2%	21.4%	23.3%	23.7%
Population 65 years and older	13.8%	15.0%	13.9%	13.4%
Median Age	37.4	39.3	38.2	37.3
Persons under age 65 living with a disability	n/a*	10.3%	11.1%	8.4%
Language other than English spoken at home	5.1%	6.7%	6.6%	20.7%
Race				
White	76.3%	74.9%	78.2%	74.0%
African American/Black	20.1%	20.1%	16.8%	12.6%
Asian	1.3%	2.0%	1.5%	4.9%
American Indian/Alaska Native	0.3%	0.2%	0.3%	0.8%
Some other race	0.9%	1.4%	1.5%	4.9%
Two or more races	1.1%	1.4%	1.7%	2.8%
Ethnicity				
Hispanic/Latino	1.8%	4.6%	4.7%	16.6%
Education, persons 25+				
Less than high school	19.3%	13.7%	15.7%	13.9%
High School graduate or higher	80.7%	86.2%	84.4%	86.3%
Bachelor's degree or higher	23.9%	27.2%	23.8%	28.8%
Economic Indicators				
Unemployed (% of civilian labor force)	3.5%	9.5%	10.1%	9.7%
Median household income	$38,930**	$46,702	$44,298	$53,046
Persons living below poverty	12.1%	16.6%	17.6%	15.4%
Children (18 or under) living below poverty	17.0%	25.3%	25.3%	21.6%
Home ownership rate	64.5%	64.9%	67.8%	64.9%

Sources: U.S. Census Bureau: 2000 Census and 2009-2013 American Community Survey
* The U.S. Census Bureau used a different measure for reported disability the 2000 Census.
**Adjusted for inflation, the 2000 median household income for Hamilton County equals $54,436 in 2013 dollars.

Table 2. Summary of Chronic Disease Risk Factors

	Hamilton	Tennessee	United States
Adult Risk Factors (Year)	**2011-2013**	**2011-2013**	**2011-2013**
Current Smoker	23%	24%	20%
Smokeless Tobacco User	4%	5%	N/A
Overweight or Obese (BMI 25+)	66%	67%	64%
Obese (BMI 30+)	29%	31%	28%
No Leisure Physical Activity	31%	34%	25%
5+ Daily Servings Fruits/Vegetables	13%	9%	N/A
Hypertension	35%	39%	31%
High Blood Cholesterol	35%	39%	38%
Binge Drinker	10%	10%	17%
Youth Risk Factors (Year)	**2011**	**2011**	**2011**
Current Smoker	17%	22%	18%
Smokeless Tobacco User	11%	13%	8%
Overweight or Obese (BMI $\geq$ 85th	27%	33%	28%
Obese (BMI $\geq$ 95th percentile)	12%	15%	15%
Insufficient Aerobic Physical Activity§	75%	75%	73%
Over 2 hrs. non-school related computer/computer games per day	26%	30%	31%
5+ Daily Servings Fruits/Vegetables	20%	22%	
Binge Drinker	18%	19%	22%
Rarely/Never Wear Seatbelt	7%	11%	8%
Rode w/driver under influence	21%	20%	24%
Physical Fight past 12 months	32%	31%	33%

Table 3. Leading Causes of Death: Age-adjusted deaths per 100,000

Rank	Cause of Death	Hamilton County 2011-2013	Tennessee 2011-2013	United States 2013
1	Heart Disease	177.1	202.7	169.8
2	Cancer	172.3	186.2	163.2
3	Chronic Lower Respiratory Disease	51.3	52.3	42.1
4	Accidents/Unintentional Injuries	44.3	51.3	39.4
5	Stroke	42.1	44.7	36.2
6	Alzheimer's Disease	39.6	37.4	23.5
7	Diabetes	28.0	25.1	21.2
8	Suicide	14.4	14.5	12.6
9	Nephritis	12.0	13.3	13.2
10	Liver Disease	10.7	12.9	10.2

Sources: Tennessee Department of Health, Division of Policy, Planning and Assessment and National Vital Statistics Reports, Volume 64, Number 2, CDC.

Table 4. Ten Leading Causes of Death in Hamilton County by Race Age-adjusted Rates per 100,000 Population 2013

	White		Black	
	Rate	Rank	Rate	Rank
Heart Disease	173.4	1st	207.1	1st
Cancer	170.1	2nd	198.0	2nd
Chronic Lower Respiratory Disease	54.4	3rd	38.8	6th
Accidents	48.6	4th	33.2	7th
Stroke	40.0	5th	52.7	4th
Alzheimer's Disease	39.9	6th	41.8	5th
Diabetes	22.5	7th	60.9	3rd
Suicide	17.1	8th	5.1	*
Liver Disease	11.3	9th	9.2	10th
Nephritis (Kidney Disease)	8.9	10th	31.7	8th
Homicide	3.3	*	27.1	10th

*Not among top ten for that race.
Source: Tennessee Department of Health, Division of Policy, Planning and Assessment

Table 5. Ten Leading Causes of Death in Hamilton County by Sex Age-adjusted rates per 100,000 population 2011-2013

	Male		Female	
	Rate	Rank	Rate	Rank
Heart Disease	224.8	1st	141.5	2nd
Cancer	216.9	2nd	143.9	1st
Chronic Lower Respiratory Disease	60.0	3rd	46.5	3rd
Accidents	58.4	4th	31.6	6th
Stroke	43.9	5th	39.7	5th
Alzheimer's Disease	30.7	6th	44.0	4th
Diabetes	30.2	7th	25.5	7th
Suicide	25.4	8th	4.9	10th
Liver Disease	13.6	9th	7.8	9th
Nephritis (Kidney Disease)	14.9	10th	10.0	8th

Table 6. ***Estimated Population of Chattanooga/Hamilton County, TN, adults 18 years and older (2013 inter-census estimate) = 268,005***

Prevalence (numbers of persons) of selected chronic conditions among adults 18 years and older living in Chattanooga/Hamilton County (2013 estimates):

Coronary Heart Disease	= 7.2% (19,296)
Stroke	= 3.8% (10,184)
Colon Cancer	= 0.0032% (857)
Breast Cancer (women only)	= 2.35% (3,149)
Type 2 Diabetes Mellitus	= 12.6% (33,769)

Table 7. ***Estimated Direct and Indirect Costs of Selected Health Outcomes (morbidity and mortality) (projected through 2020)****

Coronary Heart Disease (ICD-10: I20-I25) - $8,400 per person
Stroke (thromboembolic – ICD-10: I60-I69) - $18,400 per person
Colon Cancer (ICD-10: C18-C21) - $8,000 per person
Breast Cancer (women only – ICD-10: C50) - $8500 per person
Type 2 Diabetes (ICD-10: E11) - $16,325 per person

***CDC Chronic Disease Calculator** https://www.cdc.gov/chronicdisease/calculator/ [13]

Table 8. ***Estimated Direct Medical and Indirect Costs Associated with Selected Chronic Diseases Among Adults 18 Years and Older Living in Chattanooga/Hamilton County (2013) projected through 2020***

Coronary Heart Disease -	$162.1M (~$54M per year)
Stroke -	$187.4M (~$62.3M per year)
Colon Cancer -	$7M (~$2.3M per year)
Breast Cancer in women -	$26.8M (~$9M per year)
Type 2 Diabetes Mellitus -	$551.3M (~$184M per year)

Table 9. ***Physical Inactivity Population Attributable Fraction (PAF) for Selected Health Outcomes***

PAF formula:

$$\mathrm{PAF} = P_d \; \frac{(RR_{adj} - 1)}{RR_{adj}} \times 100\%$$

P_d – % inactive among persons who eventually develop outcome (**not** among population)

RR_{adj} – adjusted RR, inactive vs. active

Physical Inactivity PAF Selected Health Outcomes among Chattanooga/Hamilton County Adults 18 years and older – Estimated prevalence of inactivity = 31% (2013)

Coronary Heart Disease – RR = 1.33

PAF = .31 (1.33-1)/ (1.33-1) + 1 x 100% = 7.69%

Stroke – RR = 1.27

PAF = .31 (1.27-1)/ (1.27-1) + 1 x 100% = 6.59%

Colon Cancer - RR = 1.38

PAF = .31 (1.38-1)/ (1.38-1) + 1 x 100% = 8.53%

Breast Cancer in women – RR = 1.34

PAF = .31 (1.34-1)/ (1.34-1) + 1 x 100% = 7.86%

Type 2 Diabetes Mellitus – RR = 1.63

PAF = .31 (1.63 – 1)/ (1.63-1) + 1 x 100% = 11.98%

*Sources: Lee I-M, Shiroma EJ, Lobelo F, Puska P, Blair SN, Katzmarzyk PT, for the Lancet Physical Activity Series Working Group. Effect of physical inactivity on major non-communicable diseases worldwide: an analysis of burden of disease and life expectancy. *Lancet* 2012;380: 219-229.

Physical Activity Guidelines Advisory Committee. Physical Activity Guidelines Advisory Committee Report, 2008. Washington, DC: U.S. Department of Health and Human Services, 2008.

** Please refer to the attached Census Tract-specific estimates for physical inactivity to calculate Census Tract-specific PAF’s

Table 10. ***Physical inactivity related costs per chronic disease condition among Chattanooga/Hamilton County adults 18 years and older (2013) (projected through 2020)***

Coronary Heart Disease (ICD-10: I20-I25) - 1484 persons x $8400	=	$12.5M
Stroke (ICD-10: I60-I69) - 671 persons x $18,400	=	$12.4M
Colon Cancer (ICD-10: C18-C21) - 73 persons x $8000	=	$585K
Breast Cancer (women, ICD-10: C50) - 248 women x $8500	=	$2.1M
Type 2 Diabetes (ICD-10: E11) - 4046 persons x $16,325	=	$66.1M

Table 11. ***Estimated Population by Chattanooga/Hamilton County Census Tract, among Adults 18 years and older (2013 inter-census est.) Potentially Most Affected by Existing and Proposed Bicycle and Pedestrian Infrastructure, and Park Space***

Census Tract 16 = 1867 residents

Census Tract 18 = 2233 residents

Census Tract 19 = 2735 residents

Census Tract 20 = 1005 residents

Table 12. ***Estimated Direct Medical and Indirect Costs of Selected Health Outcomes by Census Tract (projected through 2020)***

Census Tract 16

Coronary Heart Disease	= 88 people x $8400 per person = $739,200.00
Stroke	= 24 people x $18,400 per person = $441,600.00
Colon Ca	= 6 people x $8,000 per person = $48,000.00
Breast Ca (women)	= 21 women x $8500 per person = $178,500.00
Diabetes (type 2)	= 138 people x $16,325 per person = $2,252,850.00

Census Tract 18

Coronary Heart Disease	= 105 people x $8400 per person = $882,000.00
Stroke	= 29 people x $18,400 per person = $533,600.00
Colon Ca	= 8 people x $8,000 per person = $64,000.00
Breast Ca (women)	= 25 women x $8500 per person = $200,000.00
Diabetes (type 2)	= 165 people x $16,325 per person = $2,693,625.00

Census Tract 19

Coronary Heart Disease	= 129 people x $8400 per person = $1,083,600.00
Stroke	= 36 people x $18,400 per person = $662,400.00
Colon Ca	= 9 people x $8,000 per person = $72,000.00
Breast Ca (women)	= 31 women x $8500 per person = $263,500.00
Diabetes (type 2)	= 202 people x $16,325 per person = $3,297,650.00

Census Tract 20

Coronary Heart Disease	= 47 people x $8400 per person = $394,800.00
Stroke	= 13 people x $18,400 per person = $239,200.00
Colon Ca	= 4 people x $8,000 per person = $32,000.00
Breast Ca (women)	= 11 women x $8500 per person = $93,500.00
Diabetes (type 2)	= 75 people x $16,325 per person = $1,224,375.00

Table 13. ***Current physical inactivity estimates, estimated physical inactivity change by exposure to improved pedestrian and bicycle infrastructure, and recalculated physical inactivity level for Census Tracts 16, 18, 19, and 20, within Chattanooga/Hamilton County Among Adults 18 years and older (2013) – See Figures 1, 2, 3, 4***

Census Tract #	Current Inactivity	Estimated Change	Recalculated Inactivity
16	52.7%	- 25.5%	27.2%
18	20.3%	- 9.8%	10.5%
19	52.7%	- 25.5%	27.2%
20	31.5%	- 15.2%	16.3%

Table 14. ***Physical inactivity PAF and costs per chronic disease condition by selected Census Tracts, Chattanooga/Hamilton County, TN***

Current physical inactivity PAF and cost (direct and indirect) for selected health outcomes for Census Tracts 16, 18, 19, and 20 of Chattanooga/Hamilton County among adults 18 years and older

Tract #	PAF CHD (cost)	PAF Strk (cost)	PAF CoCa (cost)	PAF BrCa (cost)	PAF T2DM (cost)
16	14.8% ($109K)	12.5% ($55K)	16.7% ($8K)	15.2% ($27K)	24.9% ($561K)
18	6.3% ($56K)	5.2% ($28K)	7.2% ($5K)	6.5% ($13K)	11.3% ($304K)
19	14.8% ($160K)	12.5%($83K)	16.7% ($12K)	15.2% ($40K)	24.9% ($821K)
20	9.4% ($37K)	7.8% ($19K)	10.7% ($3K)	9.7% ($91K)	16.6% ($203K)
Total Cost	$363K	$185K	$28K	$171K	$1.9M

Chattanooga Regional (tracts 16, 18, 19, 20) Costs for 5 Chronic Diseases through 2020 = $2.7M

Recalculated physical inactivity PAF + cost (direct and indirect) for selected health outcomes following improved pedestrian/bicycle infrastructure for Census Tracts 16, 18, 19, and 20 of Chattanooga/Hamilton County among adults 18 years and older

Tract #	PAF CHD (cost)	PAF Strk (cost)	PAF CoCa (cost)	PAF BrCa (cost)	PAF T2DM (cost)
16	8.2% ($61K)	6.8% ($30K)	9.4% ($4.5K)	8.5% ($15K)	14.6% ($329K)
18	3.4% ($28K)	2.8% ($15K)	3.8% ($2.4K)	3.8% ($8K)	6.2% ($167K)
19	8.2% ($89K)	6.8% ($45K)	9.4% ($7K)	8.5% ($22.4K)	14.6% ($481K)
20	5.2% ($21K)	4.3% ($10.3K)	5.9% ($2K)	5.3% ($5K)	9.5% ($116K)
Totals	$200K	$100.3K	$16K	$50.4K	$1.1M

Chattanooga Regional (Tracts 16, 18, 19, 20) costs for 5 Chronic Diseases = $1.5M

Projected cost savings in direct medical costs and indirect costs due to decreased physical inactivity/increased physical activity:

$2,700,000 (current projected costs) - $1,500,000 = $1,200,000 savings in direct and indirect medical care costs through 2020

Table 15. ***Costs and Projected Costs of Bicycle and Pedestrian Infrastructure Target Projects in Chattanooga/Hamilton County, TN***

1. Tennessee RiverWalk Extension – Ross' Landing @ Riverfront Parkway to the Wheland Foundry Trailhead - adjacent to St. Elmo Avenue – total distance, 3 miles. Geographic areas potentially most affected (Census Tracts 16, 18, 19, 20) – total cost, $16M
2. Proposed park and rail-to-trail conversion connection to the RiverWalk Extension:
    a. Park (Bell Middle School Location, Census Tract 19)
        i. Total estimated construction cost $887,000 (funded initiative)
        ii. Projected construction completion – 07/01/2017

b. Proposed Rail-to-Trail spur connection to the RiverWalk Extension
    i. ROW Acquisition: $800,000
    ii. Design and Construction: $2,052,285
    iii. Total: $2,852,285

3. Total infrastructure costs = $19,739,285
4. Indirect benefits (unmeasured) – increased tourism; improved QOL; Decreased pedestrian and bicycle morbidity and mortality; improved air quality; decreased asthma emergencies
5. Direct and indirect cost benefits due to decreased physical inactivity/increased physical activity = $1,200,000 through 2020

Projected Physical Activity Increase Effect Size for Pedestrian and Bicycle Infrastructure

1. Street-scale urban design/land-use interventions – median effect size = 48.4%

* source: Heath GW, Brownson RC, Kruger J, Miles R, Powell KE, Ramsey LT. The Effectiveness of Urban Design and Land Use and Transport Policies and Practices to Increase Physical Activity: A Systematic Review. Journal of Physical Activity and Health. 2006;1: S55-S71.

Figure 5.

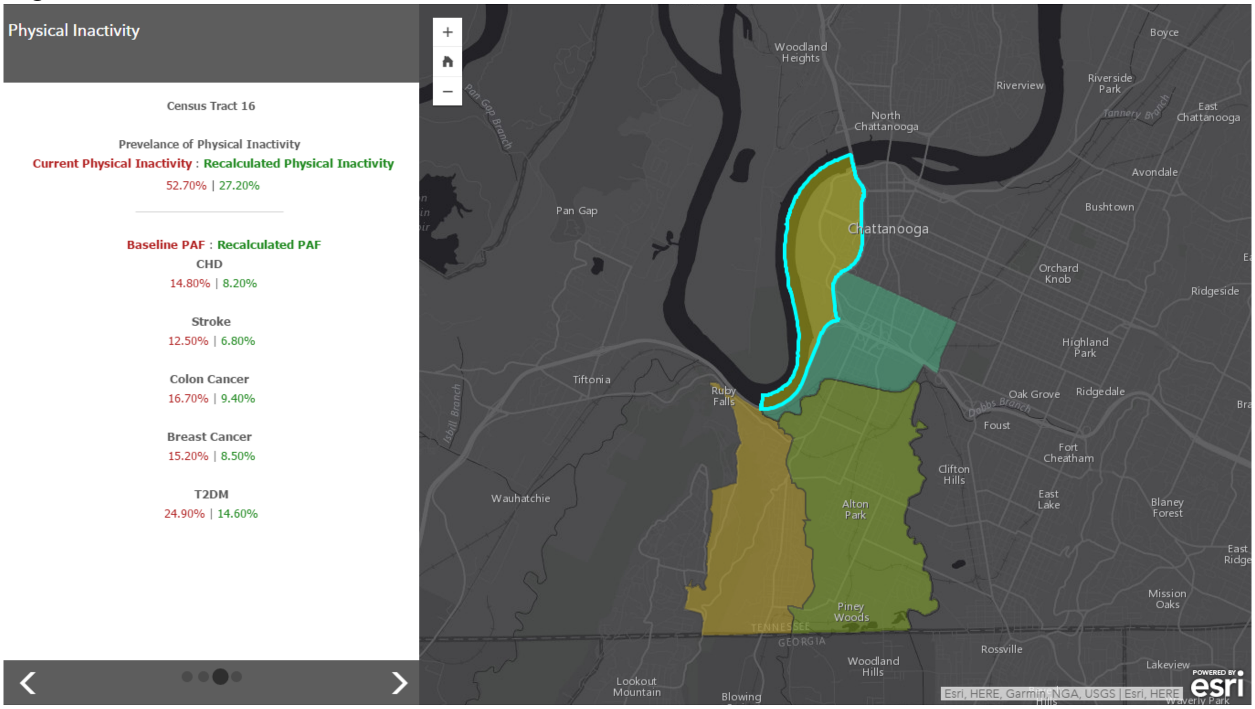


Figure 6.

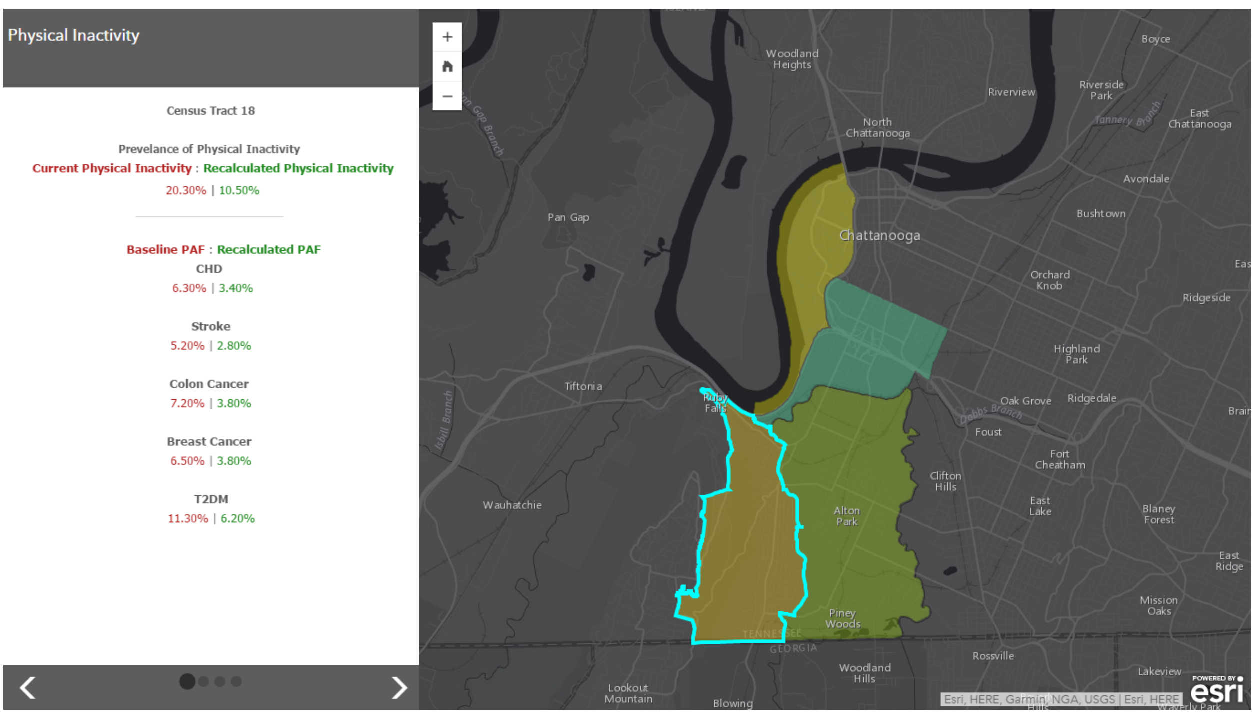


Figure 7.

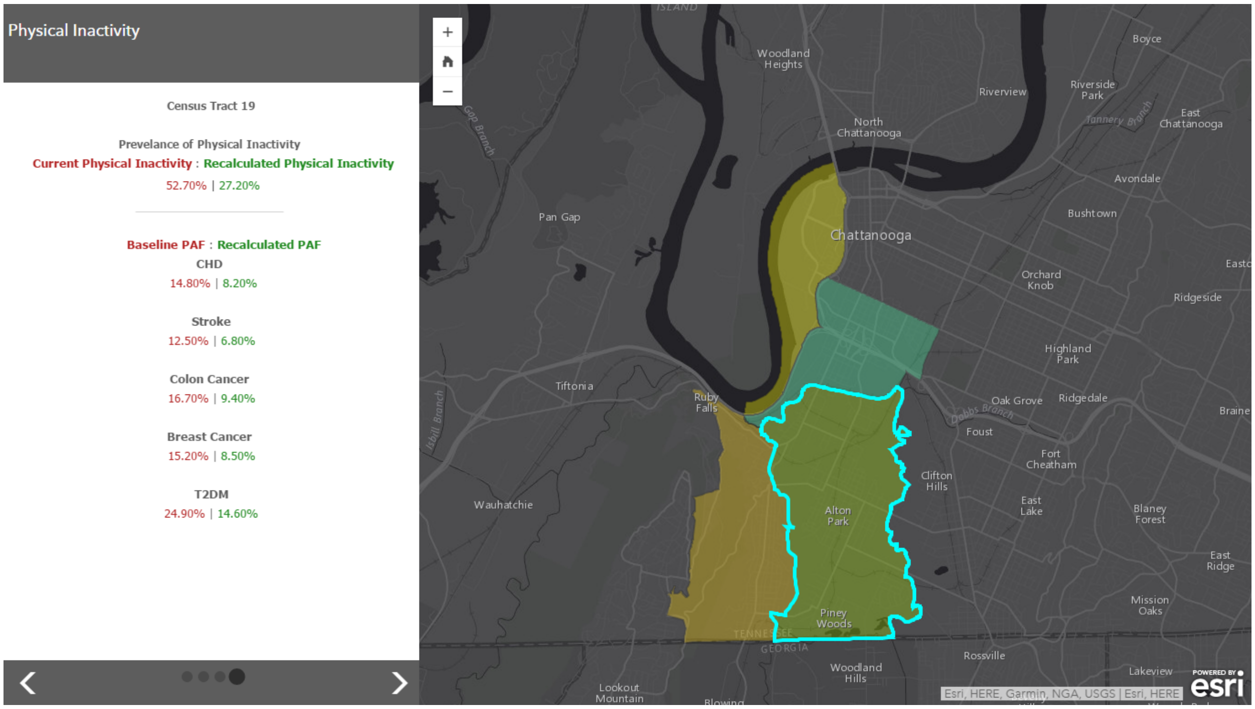
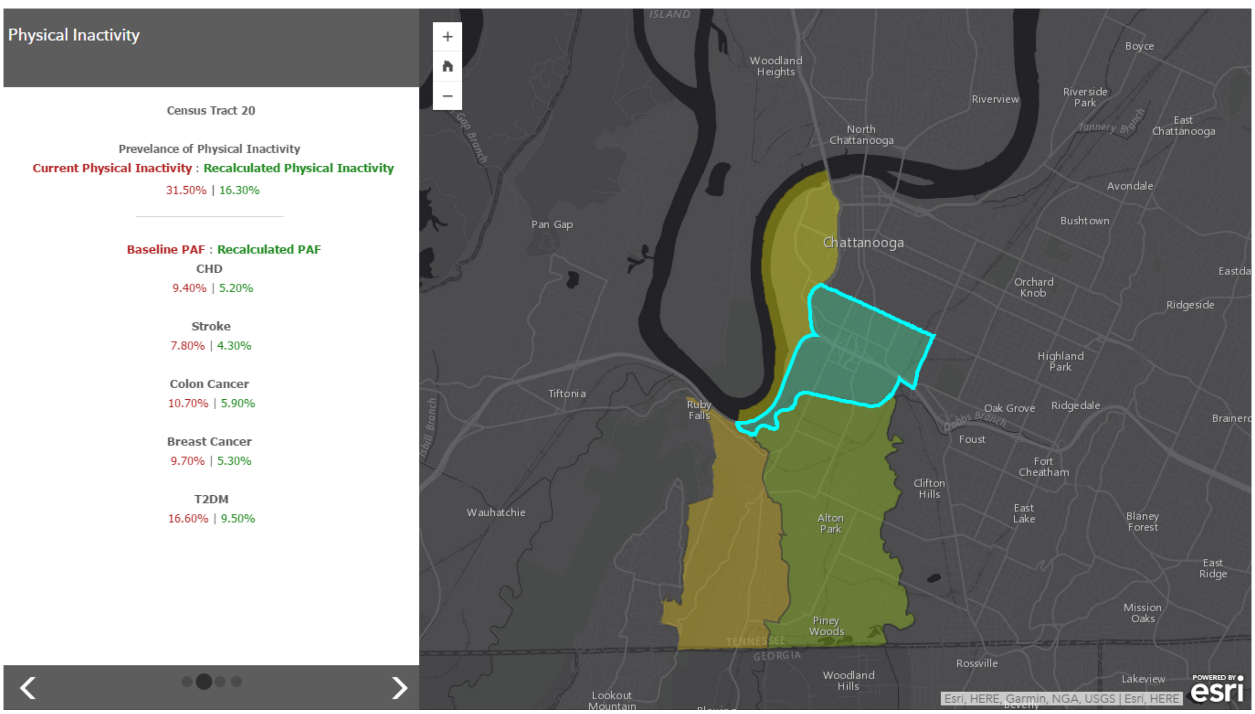


Figure 8.



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[2] G. W. Heath, D. C. Parra, O. L. Sarmiento, L. B. Andersen, N. Owen, S. Goenka, F. Montes and R. C. Brownson, "Evidence-based intervention in physical activity: lessons from around the world," *The lancet,* vol. 380, no. 9838, pp. 272-281, 2012.

[3] I.-M. Lee, E. J. Shiroma, F. Lobelo, P. Puska, S. N. Blair and Peter T Katzmarzyk, "Effect of physical inactivity on major non-communicable diseases worldwide: an analysis of burden of disease and life expectancy," *The lancet,* vol. 380, no. 9838, pp. 219-229, 2012.

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Center for Excellence in Applied Computational Science & Engineering

CUMULATIVE FINAL REPORT

(Submit as a Microsoft Word document [not PDF] via e-mail to Tony-Skjellum@utc.edu with a copy to Joanne-Romagni@utc.edu)

PROJECT OVERVIEW

Lead PI	*List personnel as you would like for them to appear in a formal report – e.g., Dr. John Smith / John Smith, PhD, etc.* T. Daniel Loveless, Ph.D.
Co-PI(s)	N/A
Other Personnel	*Identify by type – senior personnel, technicians, graduate students, undergraduate students* Graduate Students: Amee Patel, Matthew Joplin Undergraduate Students: Ellis Richards, Ryan Boggs
Project Title	Modeling Space and Defense Environmental Effects in Emerging Integrated Circuit Technologies
Date Submitted	August 30, 2017
Award Start - End Date	July 1, 2016 – June 30, 2017
Non-Technical Summary – 500 words or less	*Please provide a non-technical summary of your project that addresses the major objectives, accomplishments, and outcomes of your project. Discuss impacts of the project in terms of scholarly contributions to the field, scholarly outputs, student and community impacts, etc. Address how your project advanced or supported the mission of the SimCenter.* Typical electronics reliability modeling tools reside in a proprietary industry setting, employ techniques for a specific need, and are inappropriate for emerging integrated circuit technologies. Further, current methods involve extrapolation of short-term degradation profiles for predicting long-term behavior and lead to inaccurate and over constrained reliability predictions, and significantly limit the use of emerging integrated technologies in large distributed systems. This effort involved development of a stochastic based modeling technique for capturing intrinsic parameter fluctuations that account for time-dependent workload conditions influencing electronics reliability. Further, a novel method for measuring the stochastic behavior of atomic-level defects within electronics devices was developed. The hardware was provided to Sandia National Laboratories for measurement of time-dependent reliability in advanced and emerging semiconductor technologies. Future work will involve the collection of data for further improvement of the stochastic models, and the integration of the models into industry-standard simulation tools. This work offers a fundamentally new approach to evaluating system-level reliability vulnerabilities, enabling new approaches for mitigation, and has the potential for transforming

	the way industry assesses electronic device, component, and system reliability.
Project Web Page(s)	*Please provide the complete URL.* N/A

Please attach a Quad Chart using the following format as an example:
http://www.usamraa.army.mil/pages/baa_paa/fy06quaddirections_jsto_baa.pdf.

ACCOMPLISHMENTS & OUTCOMES

Project Overview

Provide a scientific / technical overview of your research project – hypothesis or scientific aims, methodologies and activities, outcomes, etc.

Moore's Law scaling has been predicted to be at its end for years; yet, disruptive integrated circuit technologies such as the multi-gate transistor (FinFET), fully depleted silicon on insulator (FDSOI), and the gate-all-around transistor (GAAFET) have provided avenues for continued technology scaling. While scaling and performance continues to improve, these emerging technologies have introduced new reliability concerns, illustrating the need for aggressive feasibility studies. Process-induced variability, device-level reliability, and back-end-of-line limitations have been identified as bottlenecks to system reliability, introducing a stochastic nature to device and chip functionality. Moreover, stochastic behavior has a larger effect in the low-voltage designs prevalent in highly scaled Si and emerging next generation electronics when compared to higher voltage technologies. This disruption necessitates that (1) new techniques are required for measurement of stochastic time-dependent defects, (2) a framework for understanding the statistical variation in dominant device-level reliability failure mechanisms in emerging and disruptive technologies is needed for higher-fidelity predictions of lifetime, and (3) a fundamental understanding of the interplay of variability, operational constraints, and device performance is required for development of future electronics infrastructure.

Progress towards these goals was accomplished through the integration of analytical and computational modeling techniques, and experimental design. The PI (1) developed a time-dependent defect instrument for measurement of the stochastic atomic level defects in advanced FinFET and FDSOI devices at feature sizes of 14 nm and below, and (2) developed a stochastic-based modeling technique for describing the reliability failure mechanisms. The models were designed to be compatible with industry-standard circuit simulation software and provide a unique opportunity for future development of tools for early reliability evaluation of devices and ICs designed to tackle impending scaling limitations. The work generated broad hypotheses about the stochastic nature of reliability failure mechanisms and has the potential to transform the way industry assesses electronics reliability. Further, the stochastic methodology is technology agnostic and will allow for rapid expansion into emerging technologies such as nanowires and quantum computing.

Students at the undergraduate and graduate levels were involved in all phases. Further, the work was conducted in collaboration with academic and industrial leaders in the area of high reliability, low power microelectronics.

Details on the two primary tasks are as follows:

1) **Task 1: Design and fabricate novel instrument for detection of time-dependent defects.**

Conventional empirical measurements of shifts in performance parameters (such as threshold voltage and gate leakage current) in response to stress conditions involve capturing parametric shifts during the onset of failure, which have been shown to exhibit sudden and permanent damage. Moreover, works have shown that the measured threshold has marginal impact on the lifetime due to the dependence on operational state (voltage, temperature, etc.) and the extrapolation required to predict time-to-failure [1]. Further, many reliability mechanisms are difficult to measure due to the fast recovery once stress conditions are removed. This task focused on the development of a fast measure-stress-measure (MSM) technique to observe both stress-induced degradation and defect recovery mechanisms under 1 µsec timescales. Rather than performing DC current-voltage (I-V) measurements at each stress step, the threshold voltage will be directly measured in the time domain during stress and recovery by biasing the devices with a precision current at or around threshold. Such an approach is weakly dependent on changes in mobility [2] and is conducive to obtaining stochastic profiles of the defect capture and emission times.

Figure 1 shows preliminary results from the MSM method designed to capture the current near threshold (as an alternative to the direct measure of threshold voltage previously described). Recovery transients for 6 pMOSFET devices fabricated in a 32 nm SOI process are shown following 10 sec of elevated temperature stress (130 °C). The gate-to-source and drain-to-source bias voltages were V_{GS} = -1.5 V and V_{DS} = 0 V, respectively. The transients show semi-discrete changes over time corresponding to the emissions of trapped charged particles. However, the MSM current technique has significant limitations at timescales less than 1 µsec. Thus, the MSM technique will be employed to directly measure the threshold voltage with fast-response operational amplifiers, minimizing parasitic elements that can contribute to measurement limitations. Figure 2 shows a simplified schematic of the MSM circuit for directly measuring the stress and recovery transients of the threshold voltage of an arbitrary device under test (DUT). This technique will allow for the capture of sub 1 µsec recovery transients, providing new insight into reliability recovery mechanisms.

The MSM instrument has been designed and is currently under fabrication at Sandia National Laboratories, where it will be utilized for measurement of 14 nm FinFET reliability degradation.

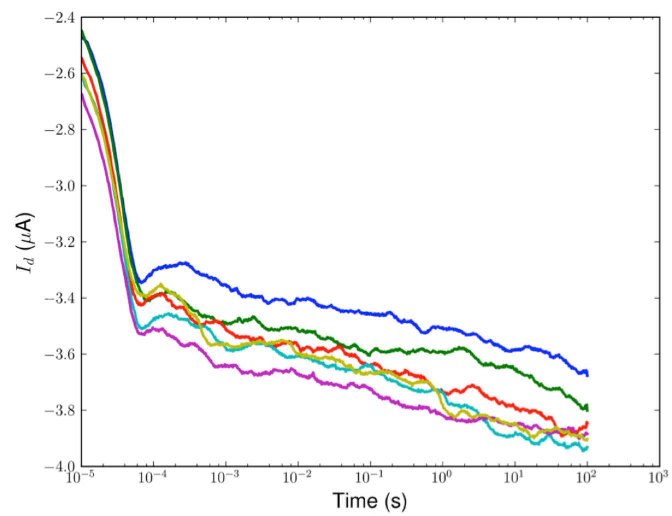

Figure 1. Recovery I_{DS} transients at threshold in 32 nm SOI pMOSFET devices following a 10 sec stress period at 130 °C (V_{GS} = -1.5 V, V_{DS} = 0 V).

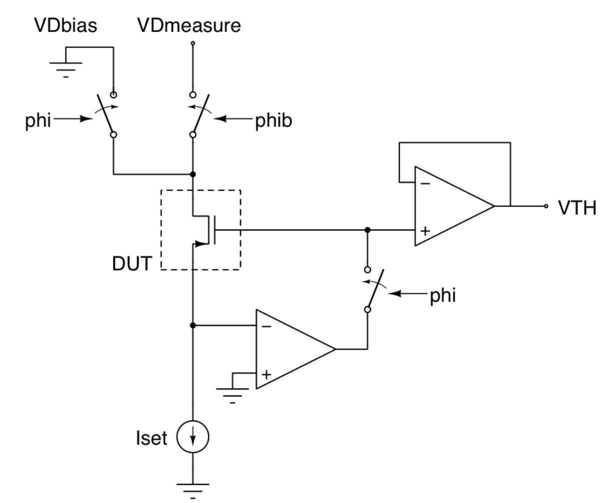

Figure 2. Simplified schematic of MSM circuit for capturing stress and recovery transients of the threshold voltage.

2) Task 2: Develop a stochastic approach to modeling variation of electrical device parameters.

The general approach is to model any given parameter of transistor *i* as a random variable ϑ_i given by (1)

$$\theta_i \ = \ \mu_{\theta,i} + \sigma_{\theta,i}(d_i) \cdot p(d_i, \phi), \theta_i \in \{ \theta_{1,} \ldots \theta_{\mathrm{M}}\} \tag{1}$$

where $\mu_{p,i}$ and $\sigma_{p,i}(d_i)$ are the mean and standard deviation of the i^{th} transistor at location d_i on die ϕ, and *p* is the corresponding stochastic process that can take the form of an appropriate statistical distribution [3]. In this way each parameter can be modeled using a generic approach that enables large-scale transparent simulations rather than through parametric sampling approaches through embedded behavioral compact models (though compact models will be used to inform initial stochastic models and determination of the stochastic parameter *p* in the absence of data). Moreover this approach will allow for the use of Bayesian inference to derive posterior probabilities that are improved with measured data. Though, initial models can be created without the need for data, thus mitigating risk associated with device procurement and experimental measurement. Data obtained from the measurements discussed in Task 2 will be used to improve the device-level stochastic reliability models.

Results: Recent work in the modeling of process variability has shown that by using a stochastic based formulation of basic process parameters, generalization of any finite number of electrical parameters θ_i can be described by a series expansion of uncorrelated random variables with deterministic functions [3]. For example, if $p(d_i, \phi)$ is a Gaussian process, then through Karhunen-Loève expansion, *M* terms of equation (1) can be expressed as (2)

$$\theta_i \ = \ \mu_{\theta,i} + \sigma_{\theta,i}(d_i) \cdot \sum_{n=1}^{M} \sqrt{\vartheta_{\theta,n}} \delta_{\theta,n}(\phi) f_{\theta,n}(d_i) \tag{2}$$

where $\delta_{p,n}(\phi)$ is a vector of uncorrelated Gaussian random variables, and $f_{\theta,n}(d_i)$ and $\vartheta_{p,n}$ are the eigenfunctions and eigenvalues, respectively, of the covariance matrix of $p(d_i, \phi)$ [3]. In other words, each parameter can be described as a random variable weighted by the distance d_i away from the reference (*e.g.*, the origin of the die ϕ). Moreover, this approach allows for expansion to any spatial domain including die, chip, and system levels and has the potential to facilitate reliability assessment of large distributed applications with joint probability models. Monte-Carlo analysis of localized basic circuit parameters such as current, voltage, and timing [4] may also be used in this context, allowing for sensitivity analyses of the modeled elements to any statistical parameter of interest.

This approach will be further expanded with the use of Bayesian inference [5][6], which derives the probability after evidence has been observed. As the initial models described by (1) and (2) will be derived from simulation data from predictive models and early manufacturing PDKs, the use of Bayesian inference will allow for refinement of the stochastic parameters based on new evidence gathered or measured. Thus, following the measurement of data *y* assumed to be representative of θ_i, one can write the posterior distribution of θ_i that depends on measurement *y* as (3)

$$p(\theta_i|y) = p(y|\theta_i)p(\theta_i)/p(y) \tag{3}$$

where $p(\theta_i)$ is the prior distribution of θ_i, $p(y|\theta_i)$ is the likelihood function of θ_i, and $p(y)$ is the probability function of measured data *y*. Using this approach, the posterior probabilities can be adjusted based on new data; this is particularly important, as reliability data is generally limited prior to technology release. Then, predictive distributions for any quantity *z* that may depend on θ_i (*e.g.*, leakage current based on threshold voltage variation) can be derived as (4).

$$p(z|y) = \int p(z|\theta_i)p(\theta_i|y)\, d\theta_i \tag{4}$$

This work served as the preliminary evidence to support a proposal to the NSF CAREER program in July, 2017. Further, collaboration with Sandia National Laboratories was established and is on-going. Sandia is in the process of integrating the instrument developed in Task 1 into their advanced device experimental flow. Data will be shared with UTC to support further model development and refinement. This stochastic approach will be used to model the dominant reliability failure mechanisms in FinFET devices. Then, the model will be generalized such that any number of chip level parameters can be included to model system level reliability of distributed systems, such as in IoT or sensor networks.

References:

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List of Objectives / Aims / Major Milestones Proposed	Cumulative Outcomes / Accomplishments
Design and fabricate novel instrument for detection of time-dependent defects.	Successful design and delivery to Sandia National Laboratories.
Describe basic stochastic approach to modeling variation of electrical device parameters on overall system reliability.	Model framework has been described analytically. Further refinement of the model will be performed following acquisition of data. Future model development will involve integration into computational tools.
Develop capability for simulation of electric behavior under simultaneous changes in process, voltage, temperature, radiation, and reliability constraints	Cadence integrated circuit design and analysis software, and Lumerical’s optical/electrical software for simulation of advanced electronic and optical devices have been acquired. Lumerical has been integrated into computing clusters at the SimCenter, allowing for finite element time domain modeling of advanced structures. Such capabilities will support model development as well as serve as a test bed for custom computational models discussed in task 2.

Add rows as needed.

Challenges & Strategies Used to Address / Overcome:

Discuss any challenges or barriers that you encountered, particularly if you were impeded from achieving the objectives and milestones approved in your proposal.

1) Acquiring data for modeling verification: Assessment of long-term degradation is challenging due to lack of data. However, collaboration with Sandia National Laboratories was established to facilitate acquisition of data on highly relevant and advanced devices. The collaboration is mutual beneficial as they receive access to the advanced instrument developed in Task 1.

2) There were issues with graduate student workers that were unanticipated. This was partly due to mismatch in skillsets, and partly due to turnover in students. This was address by hiring two undergraduate student assistants. The method was particularly effective, and had significant impact on the students. One student stayed on as a graduate research assistant at UTC, and one took a graduate research position at Vanderbilt University.

What didn't work? What did you disprove or learn from the parts that didn't meet your initial concept at the proposal?

Describe any areas where you did not meet goals; negative results are important too and should be explained and documented. Mostly, what did you learn besides what you achieved whether it met your expectations at the outset of this effort?

N/A

IMPACT & OUTCOMES

Impact on the career(s) of the PI, the co-PIs, and key collaborators	This work will provide a fundamentally new approach to evaluating system-level reliability vulnerabilities, enabling new approaches for mitigation. Rather than focusing on process control, this work will provide a means to quantify the physical limitations of variability with respect to the impact on system reliability. The stochastic methodology is technology agnostic and will allow for rapid expansion into emerging technologies such as quantum computing. The work utilized the PIs theoretical and experimental skills and expanded upon his established research program that focuses on high-reliability electronics systems. The research allowed the PI to maintain established collaborations and to build a foundation for future work in emerging computing technologies, placing the PI at the forefront of radiation and reliability modeling for future technology generations.

Students Impacted	*Please list students including name, brief description of how they were impacted, what degree sought or when graduated, and any other relevant details.* **Amee Patel:** Mrs. Patel was partially funded by the award and facilitated student training on relevant software for the design of the MSM instrument. Mrs. Patel graduated with her M.S. degree in Electrical Engineering and took a position as an embedded systems designer for La-Z-Boy furniture. **Ellis Richards:** Mr. Richards was partially funded by the award as an undergraduate student. He utilized the Lumerical software suite for simulation and analysis of photonic structures. After graduation Ellis received a stipend position at Vanderbilt University where is studying radiation effects and reliability. **Matthew Joplin:** Mr. Joplin was partially funded by the award and was responsible for the design and layout of the MSM instrument. Matt is a current graduate student. **Ryan Boggs:** Mr. Boggs was partially funded by the award as an undergraduate student. He has continued with efforts started by Ellis, and is now a graduate student at UTC. Ryan is also supporting the modeling effort.
Community and Broader Impacts	*Consider and discuss the technical and actual or potential societal impacts of your research project.* This effort enhanced students' theoretical foundations in STEM and introduced students to practical engineering under tight design constraints imposed by high-reliability and low-power operation. Students had the opportunity to work with industry leaders and received training in model development, experiment design, analysis, testing, and technical writing. The project provided students with opportunities to explore high reliability systems, such as those encountered in space systems, well before typical exposure.
Work products reduced to practice; provide a bibliographical entry where appropriate	*Please include software, papers, presentations, posters, and creative works. Indicate Refereed Journal, Refereed Conference, Non-refereed Conference for each publication listed. For journal publications, indicate the impact factors where appropriate.* 1) The MSM instrument is currently in fabrication and will be installed at Sandia as well as UTC. 2) Planned submissions to the IEEE International Reliability and Physics Symposium and the IEEE Nuclear, Space, and Radiation Effects Conference, 2018.
New inventions reduced to practice and when they will be formally disclosed;	*Please consider and include new software products that are subject to copyright but also methods and systems are potentially patentable. If you filed invention disclosures, patent or copyright applications during the period of performance, please indicate so here as well. If you wish to open source a software prototype data set, please state so; we will follow up with you with a disclosure process and guidance on how to proceed effectively for UTC and our research program, including required steps prior to doing so, and how properly to credit ownership to the UT system.* None

Outreach & Collaboration	*Please list any visitors, workshops, or other collaborative events did you hold? Indicate the location (on campus, etc.).* None

EXTERNAL FUNDING

Proposal Submissions	*Please list all sponsored program proposals submitted during the reporting period related to this or previous CEACSE awards.* CAREER: Maximizing Performance and Reliability of Advanced Electronics Technologies through Stochastic Modeling, T. D. Loveless, $500,000, Mar. 2018-Apr. 2023, pending.
Contracts / Awards Received	*List any awards or agreements received / executed related to this or previous CEACSE awards. Include sponsor name, sponsor program name (if applicable), project title, and award amount. If it is a non-funding agreement, identify by type (e.g., Data Use Agreement, Non Disclosure Agreement, Material Transfer Agreement, etc.).* None
Sponsored Program Capacity Building Activities	*List all capacity-building activities in which you have engaged during the award period. Examples may include meeting with a sponsor program officer, attending an NSF/NIH/other sponsor regional workshop, participating in GWSW activities, attending on-campus workshops, etc.* Interactions with program officers from: Defense Threat Reduction Agency (DTRA), Pauline Paki National Science Foundation (NSF), Dimitri Pavlidis, Mary Poats Participant in the Grant Writers Workshop, Grant Central Review Participant in CAREER development with the Implementation Group (TIG)

WHAT'S NEXT FOR THIS RESEARCH?

How will you follow up your CEACSE grant with work in the next 1,2, … 5 years?	This work has helped establish collaboration with Sandia, and has strengthened other collaborations by helping add value to additional programs in radiation effects and advanced integrated circuit design. Related to this work specifically, we will be following up in Sept. and Oct. with some measurements of the instrument built in task 1. Data will be used to publish articles in relevant journals and conferences, to further justify requests for funding. One submission to the NSF has been completed, directly related to this work, and more to the NSF, and other agencies such as the Missile Defense Agency, will be explored.
What other related research will you pursue (and with whom) in light of the support you've received from CEACSE?	In addition to reliability and advanced integrated circuit-related efforts, I am pursuing research related to Cyber Physical Systems, sensors, and embedded systems. Primary collaborators include Dr. Donald Reising, Dr. Mina Sartipi. However, I have pursued funding with additional collaborators such as Drs. Louie Elliott, Raga Ahmed, Nur Sisworahardjo, and Aldo McLean as well.
Tell us anything else we should know about this work not described above.	N/A
What barriers (if any) do you face to reach these next goals?	Capacity building. I have had some success in early development of a research program, and am now primarily in need of space/infrastructure to support the students and equipment acquired.

FINANCIAL ACCOUNTING

Financial Report:	**Total Award Amount:**	$25,213
	Cumulative Expenditures:	$21,632
	Remaining Award Amount:	$3,581

Please attach the following:

- *Final ledger report showing the final accounting for your award.*
- *Line item budget spreadsheet comparing your original, approved budget to how funds were actually expended.*
- *Updated budget narrative describing how funds were expended and how expense contributed to the achievement of project goals, objectives, and milestones.*

Supplemental Award Request	*Have you or do you anticipate applying for a supplemental award for any portion of the remaining balance? If so, please include the amount requested (or planned).* N/A	$3,581

THEC

Center for Excellence in Applied Computational Science & Engineering

CUMULATIVE FINAL REPORT

(Submit as a Microsoft Word document [not PDF] via e-mail to Tony-Skjellum@utc.edu with a copy to Joanne-Romagni@utc.edu)

PROJECT OVERVIEW

Lead PI	*List personnel as you would like for them to appear in a formal report – e.g., Dr. John Smith / John Smith, PhD, etc.* Donald R. Reising, Ph.D.
Co-PI(s)	Mina Sartipi, Ph.D. and T. Daniel Loveless, Ph.D.
Other Personnel	*Identify by type – senior personnel, technicians, graduate students, undergraduate students* Graduate Students: Mohammed Fadul, Amee Patel, Jin Cho
Project Title	Smart Buildings Through Smarter Models
Date Submitted	August 30, 2017
Award Start - End Date	July 1, 2016 – June 30, 2017
Non-Technical Summary – 500 words or less	*Please provide a non-technical summary of your project that addresses the major objectives, accomplishments, and outcomes of your project. Discuss impacts of the project in terms of scholarly contributions to the field, scholarly outputs, student and community impacts, etc. Address how your project advanced or supported the mission of the SimCenter.* The effort assessed current building energy models and investigated methods by which to improve them using integrated sensor data. The goal was to improve upon the existing model to facilitate real-time, high-fidelity energy usage and efficiency analysis. The existing modeling software, used in this work, requires extensive knowledge of the building's construction (e.g., materials, dimensions), occupancy, and systems (e.g., HVAC, lighting). The program then returns a projected energy usage and efficiency based upon this model; thus, the accuracy of these projections rely heavily upon the accuracy of the model. However, the sensor data facilitates direct energy usage and efficiency based upon measured values without any knowledge of the building's construction, occupancy, and systems. This project advanced the SimCenter's work within the area of Urban Systems in which energy efficiency is a key focus. This work serves as a key preliminary step in the development of a process by which to facilitate real-time, high-fidelity energy usage and efficiency analysis with the goal of improving energy usage across the community.
Project Web Page(s)	*Please provide the complete URL.* N/A

ACCOMPLISHMENTS & OUTCOMES

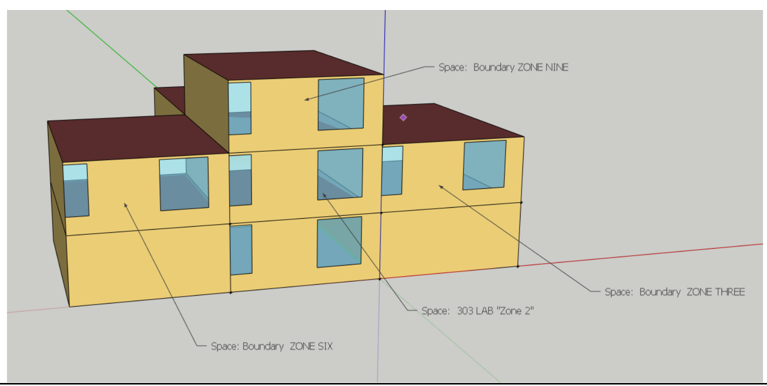
Project Overview

Provide a scientific / technical overview of your research project – hypothesis or scientific aims, methodologies and activities, outcomes, etc.

The effort assessed current building energy models as well as investigated methods, i.e., hardware, software, etc., by which to improve existing building energy models to facilitate real-time, high-fidelity energy usage and efficiency analysis. This was accomplished via three complimentary objectives:

Task 1: Assessment of Existing Building Energy Models

This task evaluated current building energy modeling techniques for explicitly determining their effectiveness in representing the energy usage and efficiency of a given building. As part of this task room 303 within the Engineering, Mathematics, and Computer Science (EMCS) building on UTC was modelled within the building energy modeling software EnergyPlus^{TM}. Generation of this model required extensive knowledge of not only the room's construction material, dimensions, its contents (e.g., lighting types, lab equipment, etc.), occupancy schedule and usage, integration of weather data, and building/room orientation (e.g., exterior wall faces north). EnergyPlus^{TM} also requires the integration of the building's systems and sub-systems, which include the heating and cooling systems and the size and type of lighting used. The heating and cooling systems were difficult to model, because many of the parameters needed were not known, easy to find, nor able to be determined. We worked closely with the Facilities Planning & Management group here at UTC to gather as many answers as possible; however, we were still unable to get all of the necessary information. Therefore, for the case of missing or unknown information, such as: service zones, number of zones, thermostat heating & cooling set points, and the Variable Air Volume (VAV) terminals and fans operating schedules, then either the default or assumed values were used. In the case of assumed values, online resources on EnergyPlus^{TM} and is associated support were used. The model required the construction of adjacent rooms. If a single room is constructed within EnergyPlus^{TM}, then it is assumed that all of the walls are exterior walls. Thus, the adjacent rooms were constructed to allow for more accurate modeling of the EMCS 303. The model constructed in EnergyPlus^{TM} is shown in Figure 1.



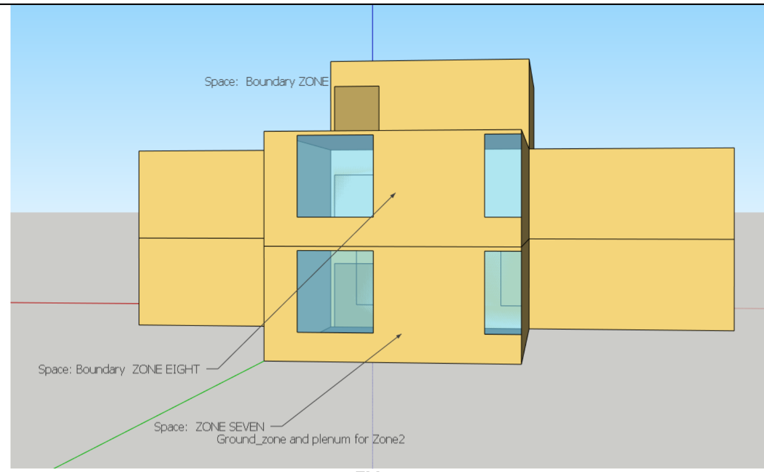


Figure 1. EnergyPlus™ 3D model of EMCS 303.

Once the EMCS 303 room model was constructed, then EnergyPlus™ was used to model the temperature and energy consumption of the room. This can be done for one day, month, and even a year. The temperature was modeled for one day, February 2, 2017, to coincide with the temperature data measured by the sensors deployed as part of Task 3. The indoor and outdoor temperature values for the February 2nd 24-hour period is shown in Figure 2. The estimated energy consumption for this same day was 4,818 kilojoules. It is important to note that the accuracy of the temperature and energy consumption is heavily reliant upon how accurately the model represents the actual room/building. In the case of this study, the users of EnergyPlus™ were neither knowledgeable of the software nor building information previously described. Therefore, it is safe to assume that the accuracy of EnergyPlus™ model is skewed, but in what ways we are not entirely sure. The real issue is the lack of an accurate baseline and model to use for comparison. Thus, future work will look to use a building (i.e., a single family home) in which all of the necessary information to construct the EnergyPlus™ model is known.

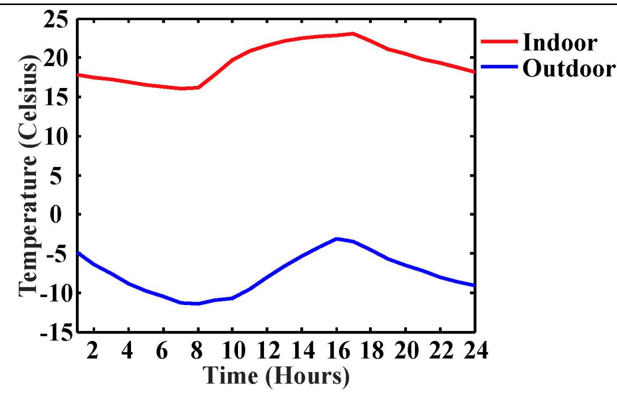


Figure 2. EnergyPlus^{TM} predicted temperature for February 2, 2017.

Task 2: Data Driven Energy Consumption Prediction

For the CEACSE smart building project, we primarily focus on energy consumption estimation by taking advantage of data-driven models. The goal is to reduce the total energy consumption of the building by estimating the A/C energy consumption, which will allow us to forecast the energy budge needed for adjusting temperature in certain areas of the building.

In reality, it is hard for us to find the complete dataset to perform such a research. Thus, we resort to the dataset provided by Pecan Street Inc. [1], to unveil the relationship between A/C energy consumption and temperature. This dataset includes hourly smart meter data for A/C energy consumption and hourly outdoor temperatures for certain houses in Austin, TX. We propose machine learning based methods (e.g., multi-layer perceptron (MLP) and long short-term memory (LSTM)) to build data-driven models. Both MLP and LSTM are implemented using Keras, a deep learning library written in Python [2]. Also, the NVIDIA GPU was utilized to speed up the computation process.

We used one house as an example to demonstrate the performances of A/C energy consumption estimation. For this house, we extracted the data from June 1st, 2014 to August 30th, 2014. The data from June 1st, 2014 to July 26th, 2014 was used for the model training purpose and the remaining data was used for model validation purpose. Previous A/C energy consumption and outdoor temperature were used as the inputs for the MLP model to estimate current A/C energy consumption. LSTM exploited outdoor temperature as the input sequence.

Table 1. The performances of A/C energy consumption estimation

	MLP	LSTM
RMSE	0.3589	0.4882
MAE	0.2559	0.3594
R^2	0.8941	0.8045

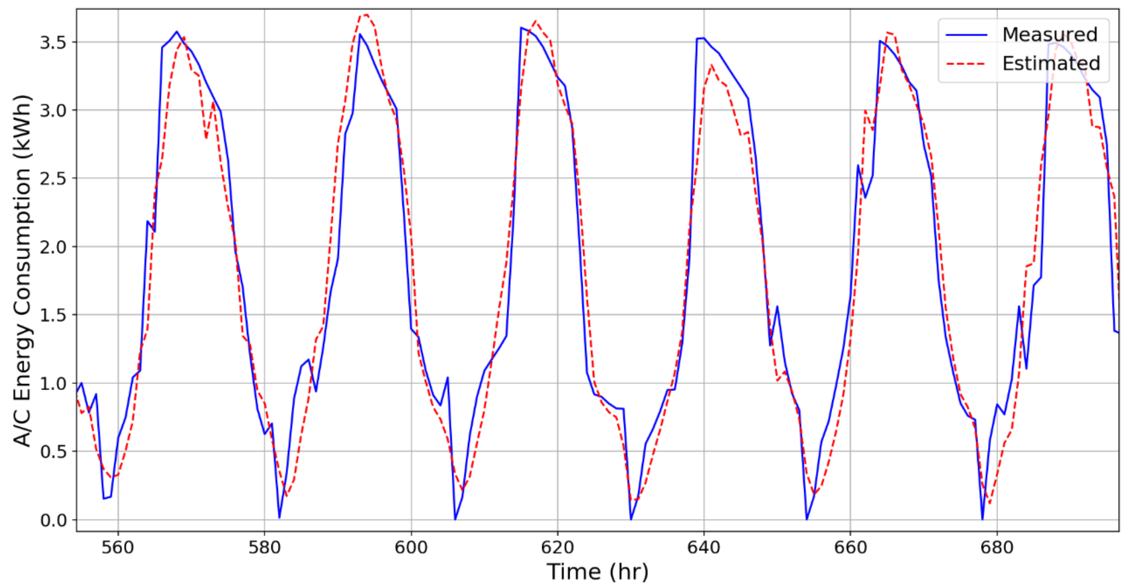


Figure 3. Estimated A/C energy consumption by MLP.

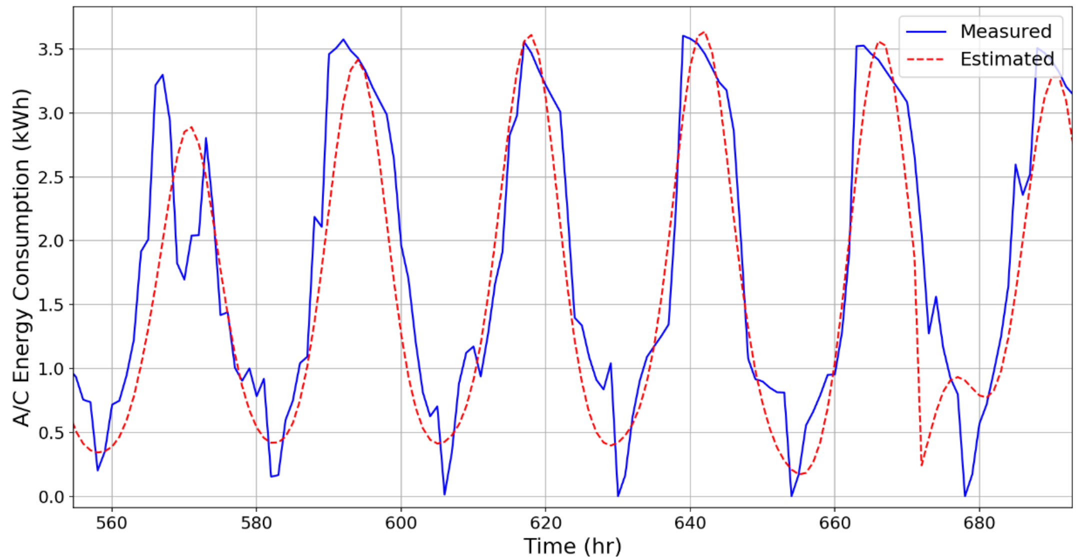


Figure 4. Estimated A/C energy consumption by LSTM

The performances of A/C energy consumption estimation are shown in Table 1. These results demonstrate the effectiveness of proposed data-driven models. Figure 3 and Figure 4 show the estimated A/C energy consumption by MLP and LSTM, respectively.

Even though the results are encouraging, there were some major limitations in this study. First, we were not able to get the A/C set points. Compared with indoor temperature, the A/C set point is more constant and has a higher correlation with A/C energy consumption. Hence, the A/C set point should be acquired as an input for the data-driven models [3], [4]. Moreover, the performances of data-driven models are highly dependent on the quality of data. In order to pursue the federal funding to further support the proposed smart building research, our next step is to build a complete/high-quality dataset with multiple data sources by exploring the latest Internet of Things technologies.

Task 3: Investigation of Smart Building CPS

In this task, a CPS-based solution comprised of networked sensors was developed for real-time acquisition of parameters relevant to energy consumption within a building. Demonstration of the concept was performed in room 303 of the EMCS building on the UTC campus. Eight low-cost wireless and wired nodes were installed for measuring temperature, humidity, and pressure. The sensors were located at the room boundaries, i.e., ceiling, walls, and floor, and one at the heating source vent. Finite difference methods were then used to approximate the solution to heat flow partial differential equations. The developed approach starts with the generation of a discrete 3D temperature distribution of the room for a specific time step using the instantaneous temperature values recorded by each of the eight sensors. Specifically, the room is represented using a 3D grid in which each point of the gird is assigned a temperature value. The temperature values assigned to each grid point are determined using steady-state analysis based upon the temperatures measured at the room boundaries by the eight sensors. The result is a 3D heat distribution of the room at a specific instance of time. For each time step, the room is sub-divided into differential sub-volumes in which each discrete temperature value, within the 3D temperature grid, serves as the respective center point. The heat flow into and out of each differential sub-volume is then approximated using basic Fourier Law and energy balance equations, resulting in consumed energy. The collection of all 3D temperature distributions with respect to time results in a temperature profile that is changing over time; thus, transient state analysis used to calculate the total energy increase in every differential sub-volume across time. Finally it is possible to estimate the total energy supplied to the room by summing the energy values across all time increments. The developed approach was used to calculate the total heating energy consumed for one day and compared to the estimated energy consumption value provided by EnergyPlus™ in Task 1.

References:

[1] "Pecan Street," [Online]. Available: http://www.pecanstreet.org.

[2] F. Chollet, "Keras," 2015. [Online]. Available: https://github.com/fchollet/keras.

[3] X. Wei, A. Kusiak, M. Li, F. Tang and Y. Zeng, "Multi-objective optimization of the HVAC (heating, ventilation, and air conditioning) system performance," *Energy,* vol. 83, pp. 294-306, 2015.

[4] K. Perez, M. Baldea and T. Edgar, "Meters to Models: Using Smart Meter Data to Predict and Control Home Energy Use," in *ACEEE 2014 Summer Study on Energy Efficiency in Buildings*, 2014.

List of Objectives / Aims / Major Milestones Proposed	Cumulative Outcomes / Accomplishments
Assessment of Existing Building Energy Models	Successfully assessed EnergyPlus™ as a means of modeling the energy consumption/efficiency of a room. EnergyPlus™ is tested and validated using industry methods such as those outlined in the American National Standards Institute (ANSI)/ American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and International Energy Agency Solar Heating and Cooling

	Programme (IEA SHC) BESTest (Building Energy Simulation Test) standards [1]. This made EnergyPlus^{TM} well-suited for use in this project.
Data Driven Energy Consumption Prediction	Successfully estimated energy consumption of the building by taking advantage of data-driven models. Using several different machine learning techniques, we were able to estimate the energy consumption with high accuracy.
Investigation of Smart Building CPS	Developed low-cost hardware for gathering data relevant to building energy consumption. Successfully demonstrated use of hardware for real-time acquisition of data relevant to modeling energy consumption. Developed model of 3 dimensional heat transfer and energy consumption using finite difference time domain (FDTD) methodologies.

Add rows as needed.

Challenges & Strategies Used to Address / Overcome:

Discuss any challenges or barriers that you encountered, particularly if you were impeded from achieving the objectives and milestones approved in your proposal.

1) The project originally targeted an entire building, but limited time and resources shifted the focus to a single building.
2) Networking the sensors throughout a building. This is limited in this effort through the use of a single room, but may become an issue as we expand the scope.
3) It was determined that the mounting location of the sensors led to induced biases within the measurements. This was very apparent for measured temperature. The constructed sensors were mounted in two ways: 1) on-board with the microcontroller, and 2) off-board and separated from the microcontroller by a wire/cable. All of the on-board temperature measurements were higher with respect to the off-board sensors. It was determined that the warmth from the microcontroller and supporting hardware led to increased temperature measurements.

What didn't work? What did you disprove or learn from the parts that didn't meet your initial concept at the proposal?

Describe any areas where you did not meet goals; negative results are important too and should be explained and documented. Mostly, what did you learn besides what you achieved whether it met your expectations at the outset of this effort?

Initially, the project was to use an entire building. However, this was an unrealistic goal based upon limited time, the number of sensors needed to instrument a building, as well as the complexity associated with the modeling and simulation tool EnergyPlus^{TM}. Limiting the project to a single room also limited the conclusions that can be drawn. We cannot predict the energy consumption for the building and it would be difficult to predict it based upon a single room. However, this work successfully served as a proof-of-concept demonstration of the proposed work and the lessons learned will be invaluable to securing external funding as well as future work.

The work also illuminated precision and accuracy challenges associated with the sensors. Although the sensors conducted a self-calibration,

there wasn't a coordinated calibration; thus, sensor dependent disparities were present within the measured data.

IMPACT & OUTCOMES

Impact on the career(s) of the PI, the co-PIs, and key collaborators	**PI:** This award served as Dr. Reising's first successful funding award since joining UTC. It also allowed the Dr. Reising to manage and guide a funded program within a simple and supportive environment. Dr. Reising's responsibilities included guiding a graduate student, writing and submitting monthly status reports, tracking expenses, keeping an up to date budget, designating tasks and roles as needed, and coordinating meetings of the research team. This experience is invaluable to Dr. Reising's success in managing, guiding, and conducting externally funded programs, which is necessary to his growth as a researcher and professor at UTC. **Co-PI (Dr. Loveless):** This project is the first successful hardware re-purposing and implementation of a real-time sensor CPS system originally designed for obtaining satellite telemetry. Thus, the effort has helped Dr. Loveless transfer technology to a new industry, broadening the impact of his former and current work. The networked array of devices and modeling efforts subsequently led to new ideas and facilitated inter-disciplinary collaboration. Further, the work has led to additional collaborative efforts amongst the investigators. **Co-PI (Dr. Sartipi):** This was a great opportunity for Mina to work with Electrical Engineering faculties, Dr. Reising and Dr. Loveless. This has opened up other opportunities that they can work together on Smart City projects with the goal of securing federal findings.
Students Impacted	*Please list students including name, brief description of how they were impacted, what degree sought or when graduated, and any other relevant details.* **Mohammed Fadul:** Mr. Fadul is seeking a Master's of Science in Electrical Engineering. Mr. Fadul carried out all of the work related to the construction of the building energy model within the modeling and simulation tool EnergyPlus^{TM}. This work pushed Mr. Fadul to work in an area in which he had little to no experience in, and he excelled. This work was invaluable to further developing his critical thinking and problem solving skills as well as transitioning from undergraduate to a graduate level of work. **Jin Cho:** Jin is finishing his Master's degree in Computer Science this fall. This was a great opportunity for him to expand his data science expertise with a real-world application. **Amee Patel:** Mrs. Patel was partially funded with the award and was responsible for the development of the networked sensor array. Her efforts with sensor calibration and network design led to completion of her degree of Masters of Science in Electrical Engineering.

Community and Broader Impacts	*Consider and discuss the technical and actual or potential societal impacts of your research project.* The potential impacts of this project is the initial development of a process by which to determine the energy usage and efficiency of a building using passive, benign sensors that require little to no knowledge of the building's construction, occupancy, and systems. The outcomes of this project are foundational to achieving energy efficient buildings within our communities.
Work products reduced to practice; provide a bibliographical entry where appropriate	*Please include software, papers, presentations, posters, and creative works. Indicate Refereed Journal, Refereed Conference, Non-refereed Conference for each publication listed. For journal publications, indicate the impact factors where appropriate.* Fadul, Mohammed, Amee Patel, Donald Reising, T. Daniel Loveless, and Mina Sartipi, "Estimating Energy Consumption Using Instantaneous Temperature Measurements", Submitted to the 2018 ASHRAE Annual Conference. Patel, Amee M., "Development of a remote IoT laboratory for cyber physical systems" (2017). *Masters Theses and Doctoral Dissertations.* Available at: http://scholar.utc.edu/theses/526
New inventions reduced to practice and when they will be formally disclosed;	*Please consider and include new software products that are subject to copyright but also methods and systems are potentially patentable. If you filed invention disclosures, patent or copyright applications during the period of performance, please indicate so here as well. If you wish to open source a software prototype data set, please state so; we will follow up with you with a disclosure process and guidance on how to proceed effectively for UTC and our research program, including required steps prior to doing so, and how properly to credit ownership to the UT system.* None
Outreach & Collaboration	*Please list any visitors, workshops, or other collaborative events did you hold? Indicate the location (on campus, etc.).* Participation in the 2017 Research Dialogues held on the UTC campus on April 11-12, 2017.

EXTERNAL FUNDING

Proposal Submissions	*Please list all sponsored program proposals submitted during the reporting period related to this or previous CEACSE awards.* NSF Smart & Connected Communities (S&CC), Solicitation 16-610 https://www.nsf.gov/funding/pgm_summ.jsp?pims_id=505364 Anticipated Dates: September 2017 – Release of RFP, November 2017 – Pre-proposal submission, February 2018 – Full proposal submission.
Contracts / Awards Received	*List any awards or agreements received / executed related to this or previous CEACSE awards. Include sponsor name, sponsor program name (if applicable), project title, and award amount. If it is a non-funding agreement, identify by type (e.g., Data Use Agreement, Non Disclosure Agreement, Material Transfer Agreement, etc.).* None
Sponsored Program Capacity Building Activities	*List all capacity-building activities in which you have engaged during the award period. Examples may include meeting with a sponsor program officer, attending an NSF/NIH/other sponsor regional workshop, participating in GWSW activities, attending on-campus workshops, etc.* Dr. Sartipi and Reising participated in "Chattanooga's Smart City Testbed" workshop on April 4, 2017. This workshop served to connect and engage a diverse group of researchers in the challenges and research opportunities surrounding "smart" city. It focused heavily on brainstorming sessions within the areas of: Transportation, Energy, and Public Health. Dr. Sartipi and Loveless participated in a "Smart Cities" workshop in May of 2017 in Cadiz, Spain. The workshop was intended to facilitate collaboration between researchers at UCA and UTC. Additionally, local government officials were present.

WHAT'S NEXT FOR THIS RESEARCH?

How will you follow up your CEACSE grant with work in the next 1,2, … 5 years?	We are currently in the process of writing a proposal that will be submitted to the National Science Foundation's Smart and Connected Communities (S&CC) Program Solicitation. The solicitation has yet to be released; however, the 2016 solicitation was released in September of 2016 with the final submission due in February of 2017. The pre-proposal for this submission is part of the Grants Writing Workshop underway here at UTC. This pre-proposal will be used to gauge program officer(s) interest as well as serve as the foundation of the full proposal.

What other related research will you pursue (and with whom) in light of the support you've received from CEACSE?	This CEACSE award actually has spurred additional work in the area of wireless device/network security (e.g., wireless sensor networks, autonomous vehicles, ad hoc wireless networks). This work directly relates to S&CC, because the concept of S&CC relies on wireless networks. These networks are cornerstones to S&CC as well as Internet of Things (IoT) and cyber-physical systems. This work currently involves the Electrical Engineering Department, and will span to include the Computer Science Department. There is also potential collaborative work with EPB, The City of Chattanooga, and Tennessee Tech in the area of S&CC.
Tell us anything else we should know about this work not described above.	This work actually served a fundamental role in determining where some of the key focus areas lie. More specifically, it identified some key challenges that must be addressed to facilitate S&CC. In addition to wireless network security, there are significant challenges surrounding the accuracy and precision of sensors. For example, in this work we used eight temperature sensors, deployed within the same room (EMCS 303). The measured temperatures, from each device, experienced up to a $15^{o}C$ temperature disparity. The other challenge involves the coordination of cyber-physical systems. This specific challenge used CPS that is unrelated or non-traditional to predict and even coordinate smart resources.
What barriers (if any) do you face to reach these next goals?	Finding the appropriate sponsoring agency as well as collaborators within the area of smart building and smart and connected communities. We are working to create these collaborations by participation in meetings and workshops whenever possible. One case of this was a meeting with Vanderbilt University, The City of Chattanooga, and the Enterprise Center on the July 27, 2017. This meeting brought to lights some potential collaboration between Andrew Rodgers of the Enterprise Center, The City of Chattanooga, and Oak Ridge National Laboratory.

FINANCIAL ACCOUNTING

Financial Report:	**Total Award Amount:**	$99,753
	Cumulative Expenditures:	$93,702
	Remaining Award Amount:	$6,051

Please attach the following:

- *Final ledger report showing the final accounting for your award.*
- *Line item budget spreadsheet comparing your original, approved budget to how funds were actually expended.*
- *Updated budget narrative describing how funds were expended and how expense contributed to the achievement of project goals, objectives, and milestones.*

Supplemental Award Request	*Have you or do you anticipate applying for a supplemental award for any portion of the remaining balance? If so, please include the amount requested (or planned).* N/A	$

THEC
Center for Excellence in Applied Computational Science & Engineering

CUMULATIVE FINAL REPORT

(Submit as a Microsoft Word document [not PDF] via e-mail to Tony-Skjellum@utc.edu with a copy to Joanne-Romagni@utc.edu)

PROJECT OVERVIEW

Lead PI	*List personnel as you would like for them to appear in a formal report – e.g., Dr. John Smith / John Smith, PhD, etc.* Mina Sartipi, Ph.D.
Co-PI(s)	Craig Tanis, Ph.D.
Other Personnel	*Identify by type – senior personnel, technicians, graduate students, undergraduate students* Undergraduate Students: Robert Barber, Caleb Campbell Graduate Students: Hector Suarez, Austin Harris
Project Title	Smart Urban Connectivity Powered by Mobility-on-Demand Public Transportation and Citywide Public Communications
Date Submitted	August 30, 2017
Award Start - End Date	July 1, 2016 – June 30, 2017
Non-Technical Summary – 500 words or less	*Please provide a non-technical summary of your project that addresses the major objectives, accomplishments, and outcomes of your project. Discuss impacts of the project in terms of scholarly contributions to the field, scholarly outputs, student and community impacts, etc. Address how your project advanced or supported the mission of the SimCenter.* In order to confront unprecedented challenges due to the rapid urbanization, we started a fundamental research on smart urban connectivity. We investigated the methodologies, feasibilities, and potentials of two essential connectivity paradigms for urban futures, i.e., cooperative mobility and citywide wireless communications. We developed a real-time graph for the streets of the city of Chattanooga that can be updated by crowdsourcing, designed personalized routing algorithms that consider features such as health, air quality, and elevation, and investigated a small testbed for advanced wireless communications. The proposed research involved computationally intensive data analytics, graph analytics, simulation and modeling, optimization, operations research, and urban planning. This project advanced the SimCenter's work within the area of Urban Systems in which transportation and wireless communications are key focuses.
Project Web Page(s)	*Please provide the complete URL.* N/A

ACCOMPLISHMENTS & OUTCOMES

Project Overview
Task I: Prototyping a data structure representing conectivity of road ways using open source maps The goal of this software development project was to prototype and populate a data structure representing the topographical layout of streets and sidewalks in Chattanooga, associating each with relevant metadata (distance, elevation, traffic conditions) and enabling efficient path searches for fleet routing. As the project concludes, we have a working prototype meeting these goals, and we have demonstrated intelligent path planning with real-world data. To accomplish these goals an adjacency list graph data structure was designed to represent intersections (vertices) and roads/sidewalks (edges) that is populated with data provided by the OpenStreetmap project. A considerable amount of time and effort was spent manually working with OpenStreetmap data feeds to populate the adjacency list data structure, rather than relying on existing third party solutions, so that other map providers could be used if needed. **Work (Java)** The following two search algorithms were demonstrated: single source shortest path and A* search algorithms with this data structure, with edge weights calculated by Euclidean distance, elevation effect heuristics and simulated traffic data. The Java portion of this project used Open Street Map (OSM) raw XML data to create a custom graph data structure(s) such as an adjacency list that can be searched using the following algorithms: A Star Search and Shortest Path Search (Dijkstra's algorithm). An advantage of designing custom data structures is that it, decouples some of the OSM layer dependencies and allows the search operations run faster as the data are in memory as opposed to being stored in a database. Another advantage to creating a custom data structure is that one can add custom attributes to the data structure such as custom graph edge weights that include weather data and traffic congestion. The programming language used for the CEACSE project was Java 8. This project made use of an open source OSM data parser called *Basic OSM Parser* to read in the OSM XML data file such as Nodes (gps coordinates) and Ways (lists of gps coordinates) . From the latter mentioned input OSM file, an adjacency list graph data structure was created or more precisely, a dictionary list in which the value(s) pair elements contain a dictionary list of the key(s) connected nodes with their respective weights as the value pair. To give a basic example of what this type of data structure looks like: [A->{B->1,C->24, E->20, F->38}, B->{A->3, C->28, F->22}]. In this adjacency list, node A is connected to the key nodes B,C,E,F with the respective value pairs: 1,24,20,38. Before,

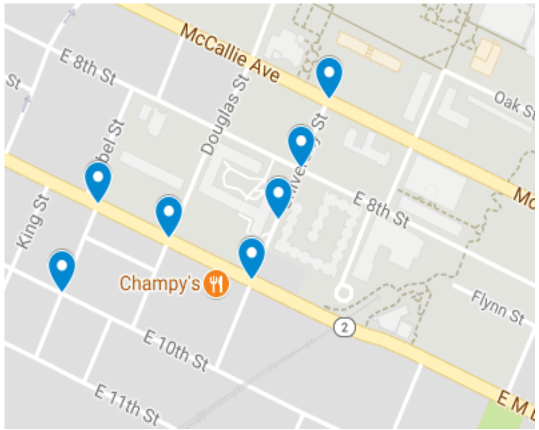
creating the search algorithms the adjacency list was packaged up in algorithms.graph package, this made the code base model more organized so that other data structures can be added to the algorithms.graph package.

The search algorithms used to find route list were A Star Search and Single Source Shortest Path search. The following, data are the route list generated from the CEACSE Java code, where Node Lat and Node Lon refer to Node Latitude and Node Longitude respectively.

Table 1. A list of Nodes along the shortest path

Node ID: N202662066	Node Lat: 35.0454582	Node Lon: -85.3003297
Node ID: N202740500	Node Lat: 35.0446116	Node Lon: -85.3007771
Node ID: N202740503	Node Lat: 35.0439783	Node Lon: -85.3011414
Node ID: N202695954	Node Lat: 35.0432349	Node Lon: -85.3015638
Node ID: N202608349	Node Lat: 35.0437446	Node Lon: -85.302903
Node ID: N202596948	Node Lat: 35.0441682	Node Lon: -85.3040337
Node ID: N202596950	Node Lat: 35.0430927	Node Lon: -85.3046207

The left map consists of the generated gps route coordinates of the Java shortest path algorithm. In order to compare the algorithms, a standard map search engine called GraphHopper was used. The map on the right used GraphHopper with the same start and end coordinates as the left map. Notice that the paths are very similar which shows that the implemented java search algorithms give realistic results.



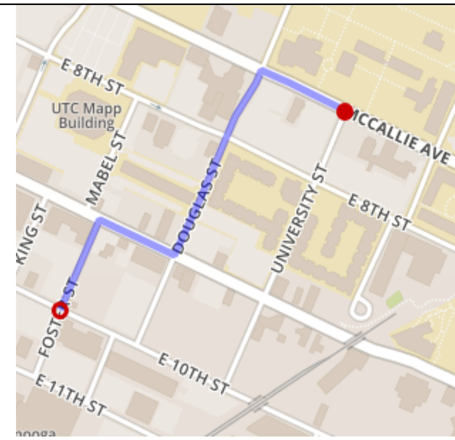


Figure 1. Java A Star Search

Work (Python)

Two Python packages (i.e., OSMNX and NetworkX) were exploited for algorithm design/development and performance visualization/validation. Data extracted from Openstreetmap was used to construct the required road/street network/graph. The single source shortest path algorithm provided by OSMNX was used in order to verify the results from the Java code. The road network used was generated from the same geographical area as used in the Java code. The application inputs are geo-coordinates of the source and destination points. The shortest path algorithm was used to generate the route from the source to the destination. A list of nodes that defines this route was used for comparison.

Table 2. A list of Nodes along the shortest path

Origin (Latitude, Longitude)	(35.045453, -85.300355)
Source Node ID	202662066
Node Path	202662066, 202740500, 202740503, 202695954, 202608349, 202596948, 202596950
Destination Node ID	202596950
Destination (Latitude, Longitude)	(35.0430927, -85.3046207)

Figure 2 illustrates the route (i.e., the shortest path) generated from the Python code. The nodes that make up this route are listed in Table 1. While the shortest path (shown in Figure 2), generated from the Java code, consists of the following nodes (202662066, 202740500, 202740503, 202695954, 202608349, 202596948, 202596950). The results generated by both Python and Java codes utilize the same nodes while traversing through the same route, which therefore proves the accuracy of the Java code. Based on the current results, we can further implement more complex functions using Java and the corresponding framework.

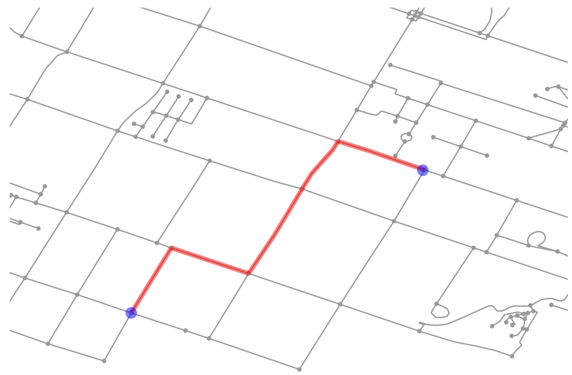


Figure 2. The OSMNX shortest path

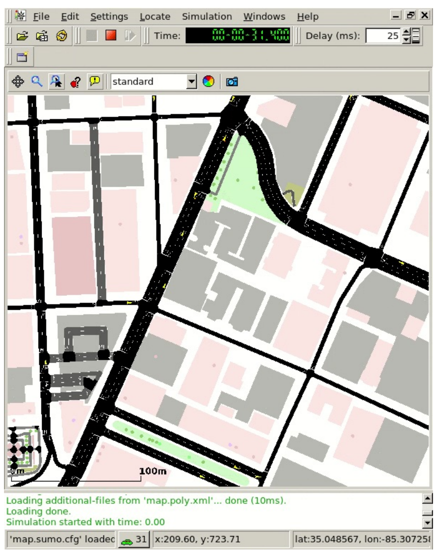
The final prototype code demonstrates the ability to successfully work with map data and arbitrary sensor data, and interesting work is yet to be done concerning meaningful multi-parameter heuristic edge weights. Going forward with this project would include refining the used API to conform to better software engineering practices and develop a scalable persistence mechanism so that this custom geographic database can be effectively used on a range of future problems.

Task II: Building a similation environment to

Next, we built a powerful/generic simulation environment to study the challenging vehicle routing problems. This simulation environment mainly includes Simulation of Urban Mobility (SUMO) and Traffic Control Interface (Traci). The routing algorithms can be written in Python. Python acts as the client which interacts with SUMO by Traci. Figure 3 shows the architecture design of Traci and SUMO. Meanwhile, Open Street Map provides data necessary for generating road networks in SUMO.

List of Objectives / Aims / Major Milestones Proposed	Cumulative Outcomes / Accomplishments
Prototyping a Data Structure to Represent the City Connectivity Graph with Relevant Metedata	Successfully prototyped and populated a data structure representing the topographical layout of streets and sidewalks in Chattanooga, associating each with relevant metadata (distance, elevation, traffic conditions) and enabling efficient path searches for fleet routing. An adjacency list graph data structure was designed to represent intersections (vertices) and roads/sidewalks (edges) that is populated with data provided by the OpenStreetmap project. A considerable amount of time and effort was spent manually working with OpenStreetmap data feeds to populate the adjacency list data structure, rather than relying on existing third party solutions, so that other map providers could be used if needed.
Developing Intelligent Path Planning	Developed intelligent path planning algorithms that successfully work with map data and arbitrary sensor data to generate meaningful multi-parameter edge weights to find personalized paths.
Cooperative Routing	Built a powerful/generic simulation environment to study the challenging vehicle routing problems with primary goal of minimizing congestion through cooperative routing. The single vehicle routing algorithms are prone to be selfish without consideration of other vehicles or the whole intelligent transportation system, which can induce many new problems. Based on this generic simulation environment, we put our research effort on cooperative routing to address the problems caused by the single vehicle routing and achieve the global optimum in some sense. For example, in a collaborative mobility-on-demand public

Vehicle routing is a well-studied problem. Traditionally, the routing for an individual vehicle mainly considered the source and destination locations and exploited the shortest path algorithm or A∗ search algorithm based on graph theory. The single vehicle routing algorithms are prone to be selfish without consideration of other vehicles or the whole intelligent transportation system, which can induce many new problems. Based on this generic simulation environment, we put our research effort on cooperative routing to address the problems caused by the single vehicle routing and achieve the global optimum in some sense. For example, in a collaborative mobility-on-demand public transportation system, we need to search for the desired routes for all the buses simultaneously with the joint consideration of demand, traffic, bus, and passenger information. Cooperative routing/rerouting is also a potential solution to congestion mitigation. If all the vehicles take their own optimal routes individually, the congestion can be formed on the road segment when the majority of vehicles pass it at almost the same time. Hence, different vehicles may be rerouted to different roads based on the objectives and constraints of the cooperative routing problem, even though the sources and destinations of these vehicles are close. Through the simulation, we can get all quantitative performance measures (such as travel distance, travel time, stop time, and pollution emission) to quantify the benefits of cooperative routing. Furthermore, this simulation environment can be used to investigate many other emerging urban/transportation-related problems, which can provide us a lot of preliminary results and valuable insights to pursue more significant/collaborative projects funded by the external funding agencies.



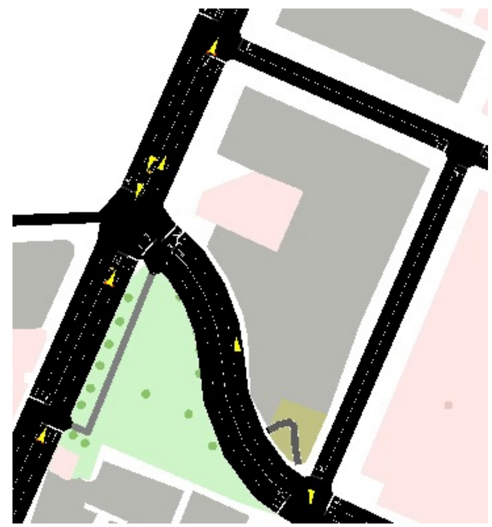


Figure 4. (a) Image of SUMO visualization, corner of Georgia Ave and McCallie Ave. This image shows SUMO's controls/graphical interface. (b) Same area as (a), but without the SUMO interface.

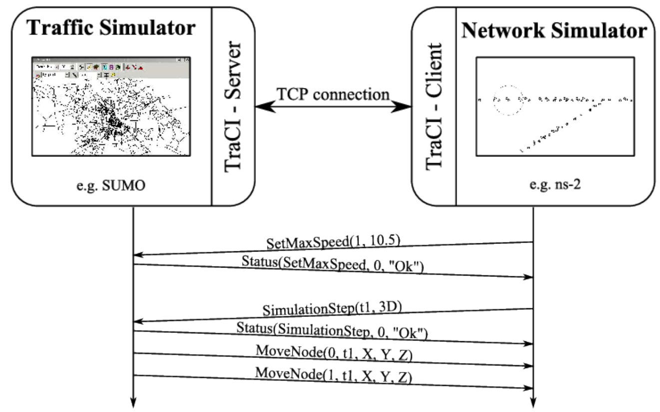


Figure 3. Architecture design of TRACI and SUMO.

SUMO is a microscopic, inter-and multi-modal and space continuous traffic flow simulation. SUMO along with other frameworks is being used to help investigate and test the cooperative routing system. SUMO is a time-discrete simulation whose time step is 1 second. Our primary goal is to minimize congestion through cooperative routing. We focus on rerouting all vehicles in the simulation at each time step based on the current state of the simulation and vehicles. As a result, the average vehicles drive distance and drive time should be reduced.

First, a geographical area was selected for the simulation. In order to import the geographical area into SUMO an application called “netgen” must be used. This application generates road networks from Open Street Map data. SUMO allows each vehicle to be defined explicitly. For our simulation, each vehicle was defined by at least a vehicle identifier, a departure time, and a source and destination. SUMO provides an API that allows for the simulation of V2X (Vehicle-to-Vehicle) and vehicle-to-infrastructure communication. This infrastructure was used to monitor, to reroute, and to control vehicles in real time. The communication infrastructure used was an application called Traci. Traci is a TCP based Traffic Control Interface that provides access to the traffic simulation. Traci commands are broken into three basic categories: Value Retrieval, State Changing, and Subscriptions.

In order to test our configuration, we started the SUMO simulation. Using Python, we create a local copy of the SUMO road network. At each step in the simulation, Traci was used to request the current state of all objects, update values to the local road network (graph) and reroute all vehicles based on the new state of the road network. Lastly, before the next step begins, the Traci interface was used to update SUMO with the new route for each vehicle.

	transportation system, we need to search for the desired routes for all the buses simultaneously with the joint consideration of demand, traffic, bus, and passenger information. Cooperative routing/rerouting is also a potential solution to congestion mitigation. If all the vehicles take their own optimal routes individually, the congestion can be formed on the road segment when the majority of vehicles pass it at almost the same time. Hence, different vehicles may be rerouted to different roads based on the objectives and constraints of the cooperative routing problem, even though the sources and destinations of these vehicles are close.
Advanced Wireless Communication (Pilot Study)	Successfully developed a small real-world testbed on a 5th street close to EMCS. Access points were places on three electrical poles distributed on 5th street. The access points allowed the use of various frequencies such as 2.4Ghz, 5Ghz, and 60Ghz. For this experiment, we focused on using 5Ghz, which allowed us to have an overlapping wireless environment either through the access points on the poles or using the router on top of the middle vehicle as a bridge between two access points. Using 5Ghz also allowed us to keep a wireless connection in the event of an object blocking the signal's direct path. Each access point was connected to Chattanooga's fiber internet connection giving the routers a maximum data transfer speed of approximately 10-Gbps. This high-bandwidth network connection vastly improved overall latency when testing with our HPC at the SimCenter, which is also connected to fiber.

Add rows as needed.

Challenges & Strategies Used to Address / Overcome:

Discuss any challenges or barriers that you encountered, particularly if you were impeded from achieving the objectives and milestones approved in your proposal.

1) Intelligent management center: Originally we planned to study demand and response, decision making for vehicle route and mobility, and personalized trip planning. Limited time and resources shift our focus to the last two items.
2) City-wide testbed: Due to limited time and budget we focus on one street on campus. Although the scale is much smaller, this is still one of very few outdoor real-world testbeds.

What didn't work? What did you disprove or learn from the parts that didn't meet your initial concept at the proposal?

Describe any areas where you did not meet goals; negative results are important too and should be explained and documented. Mostly, what did you learn besides what you achieved whether it met your expectations at the outset of this effort? While our goal was to design a mobility-on-demand shared-ride public transportation, we were limited by time and resources. We learned that the dynamic map of the city, intelligent and personalized routing algorithms were needed before we can focus on the demand and service management of the project. Furthermore, instead of testing the feasibility of small cells at the city level, we focused on one street. Through this experience we had an opportunity to work with mmWave is a real-world setting. We also learned that with number of access points we had, 60GHz was not feasible. Overall, this work successfully served as a proof-of-concept demonstration of the proposed work and the lessons learned will be invaluable to securing external funding as well as future work.

IMPACT & OUTCOMES

Impact on the career(s) of the PI, the co-PIs, and key collaborators	**PI (Dr. Sartipi):** This was a great opportunity for Mina to work with Dr. Tanis This has opened up other opportunities that they can work together on Smart City projects with the goal of securing federal findings. **Co-PI (Dr. Tanis):** This award was Dr. Tanis's first Urban Sciences project and first collaboration with Dr. Sartipi. Through this he met key participants in the regional Smart Cities initiative, and laid the groundwork for future collaborative projects.
Students Impacted	*Please list students including name, brief description of how they were impacted, what degree sought or when graduated, and any other relevant details.* Robert Barber: Robert learned more about routing algorithms as well as Python packages. After being involved in this exciting research project, Robert decided to stay for graduate school. Caleb Campbell: Caleb was able to expand her knowledge on graph theory and data structures. Hector Suarez and Austin Harris were able to work as a team on several aspects of this project. They also learned how to manage the project as at times the PI asked them to set the goals, justify them, and work with the undergraduate students on the team.
Community and Broader Impacts	*Consider and discuss the technical and actual or potential societal impacts of your research project.* Our project was a practical project with near-time payoff and as a huge step towards the larger “smart cities” goals. We have worked very closely with The Enterprise Center, EPB, and Chattanooga DOT. By prototyping a dynamic real-time map for the city of Chattanooga, investigating personalized routing algorithms, and designing cooperative routing we paved the path for our long-term goal of dynamic flexible-route public transportation which will impact all citizens of Chattanooga.

Work products reduced to practice; provide a bibliographical entry where appropriate	*Please include software, papers, presentations, posters, and creative works. Indicate Refereed Journal, Refereed Conference, Non-refereed Conference for each publication listed. For journal publications, indicate the impact factors where appropriate.* M. Sartipi, R. Thompson, "Real-Time See Through Technology for Collected Autonomous Vehicles," US Ignite Application Summit and Smart Cities Connect Conference, Live Demonstration, June 2017. M. Sartipi, "Connected Autonomous Vehicles at UTC," 1st Tennessee Connected & Automated Vehicle Summit, May 2017. R. Thompson, Z. Hu, J. Cho, J. Stovall, A. Harris, and M. Sartipi, "See-Through Technology Using V2X Communication," submitted to the ACM Mid-Southeast, August 2017.
New inventions reduced to practice and when they will be formally disclosed;	*Please consider and include new software products that are subject to copyright but also methods and systems are potentially patentable. If you filed invention disclosures, patent or copyright applications during the period of performance, please indicate so here as well. If you wish to open source a software prototype data set, please state so; we will follow up with you with a disclosure process and guidance on how to proceed effectively for UTC and our research program, including required steps prior to doing so, and how properly to credit ownership to the UT system.* N/A
Outreach & Collaboration	*Please list any visitors, workshops, or other collaborative events did you hold? Indicate the location (on campus, etc.).* Participation in the 2017 Research Dialogues held on the UTC campus on April 11-12, 2017. Organizing bi-weekly research seminars, including presenters from ORNL and UTK. Presented at the 1st Tennessee Connected & Automated Vehicle Summit on May 17, 2017.

EXTERNAL FUNDING

Proposal Submissions	*Please list all sponsored program proposals submitted during the reporting period related to this or previous CEACSE awards.* NSF Smart & Connected Communities (S&CC), Solicitation 16-610 https://www.nsf.gov/funding/pgm_summ.jsp?pims_id=505364 Pending (submitted Feb. 2017) NSF Big Data Regional Innovation Hubs: Establishing Spokes to Advance Big Data Applications (BD Spokes), Solicitation 17-546 In Collaboration with GA Tech and VA Tech (to be submitted Sept. 2017) NSF Critical Techniques, Technologies and Methodologies for Advancing Foundations and Applications of Big Data Sciences and Engineering (BIGDATA), Solicitation 17-534 https://www.nsf.gov/publications/pub_summ.jsp?WT.z_pims_id=504767&ods_key=nsf17534 Anticipated submission data, spring 2018.
Contracts / Awards Received	*List any awards or agreements received / executed related to this or previous CEACSE awards. Include sponsor name, sponsor program name (if applicable), project title, and award amount. If it is a non-funding agreement, identify by type (e.g., Data Use Agreement, Non Disclosure Agreement, Material Transfer Agreement, etc.).* N/A
Sponsored Program Capacity Building Activities	*List all capacity-building activities in which you have engaged during the award period. Examples may include meeting with a sponsor program officer, attending an NSF/NIH/other sponsor regional workshop, participating in GWSW activities, attending on-campus workshops, etc.* Dr. Sartipi participated in “Chattanooga’s Smart City Testbed” workshop on April 4, 2017. This workshop served to connect and engage a diverse group of researchers in the challenges and research opportunities surrounding “smart” city. It focused heavily on brainstorming sessions within the areas of: Transportation, Energy, and Public Health. Through this workshop we met several faculty from GaTech, Vanderbilt, UTK, VA Tech. We have started collaborating with some of these faculties/ researchers. We are identifying more collaboration opportunities. Dr. Sartipi participated in a “Smart Cities” workshop in May of 2017 in Cadiz, Spain. The workshop was intended to facilitate collaboration between researchers at UCA and UTC. Additionally, local government officials were present. Dr. Sartipi also met with Chattanooga DOT, TN DOT, ORNL Transportation for potential collaborations. Dr. Sartipi has traveled to several NSF workshops, smart city expos and has talked with several NSF program officers regarding these opportunities. She has also talked with Planning Division director of TDOT.

WHAT'S NEXT FOR THIS RESEARCH?

How will you follow up your CEACSE grant with work in the next 1,2, … 5 years?	We have submitted a proposal (S&CC), in process of submitting one more (Spokes), and in the process of writing another one that will be submitted to NSF's S&CC or BIGDATA program solicitation.
What other related research will you pursue (and with whom) in light of the support you've received from CEACSE?	We will continue our collaborations with other universities (UTK, Vanderbilt, GA Tech, VA Tech), community (EPB, The Enterprise Center, CDOT, TDOT) and look for other potential opportunities for expansion of our research work.
Tell us anything else we should know about this work not described above.	N/A
What barriers (if any) do you face to reach these next goals?	While we achieved majority of goals proposed in this project, there were few topics that weren't explored due to lack of resources and expertise. We plan to address the lack of expertise by identifying right people form other departments as well as other universities and collaborating with them. Furthermore, the testbed is very challenging. Such a testbed that satisfies the requirements in terms of latency and bandwidth doesn't currently exist at the city scale. Finding off-the-shelf equipment for this testbed will challenging as well.

FINANCIAL ACCOUNTING

Financial Report:	**Total Award Amount:**	$95,503
	Cumulative Expenditures:	$95,503
	Remaining Award Amount:	$0

Please attach the following:

- *Final ledger report showing the final accounting for your award.*
- *Line item budget spreadsheet comparing your original, approved budget to how funds were actually expended.*
- *Updated budget narrative describing how funds were expended and how expense contributed to the achievement of project goals, objectives, and milestones.*

Supplemental Award Request	*Have you or do you anticipate applying for a supplemental award for any portion of the remaining balance? If so, please include the amount requested (or planned).* N/A	$

THEC

Center for Excellence in Applied Computational Science & Engineering

CUMULATIVE FINAL REPORT

(Submit as a Microsoft Word document [not PDF] via e-mail to Tony-Skjellum@utc.edu with a copy to Joanne-Romagni@utc.edu)

PROJECT OVERVIEW

Lead PI	*List personnel as you would like for them to appear in a formal report – e.g., Dr. John Smith / John Smith, PhD, etc.* N. Sisworahardjo
Co-PI(s)	A. Arabshahi, K. Sreenivas
Other Personnel	*Identify by type – senior personnel, technicians, graduate students, undergraduate students* Akram Saad (graduate student)
Project Title	Near Real-time Detection of Anomalous Power Consumption in Smart Power Distribution Networks
Date Submitted	08/28/2017
Award Start - End Date	07/01/2016 – 06/30/2017
Non-Technical Summary – 500 words or less	*Please provide a non-technical summary of your project that addresses the major objectives, accomplishments, and outcomes of your project. Discuss impacts of the project in terms of scholarly contributions to the field, scholarly outputs, student and community impacts, etc. Address how your project advanced or supported the mission of the SimCenter.* Through this project, our team members (PI and co-PIs) gained tremendous experience in big data and data analytics and understand the possible utilization that not only limited to power industries but also in other disciplines. Strategic relationship with local industry was strengthened with extensive collaboration with EPB and provide us opportunity to further this collaboration in scholarship activities. From this grant one graduate student received full support for one year to persue his master degree. Through the project, student gained first-hand experience in research and scholarship activities. Student had opportunity to write technical report which leads to paper(s) publication in conference/journal. One paper was submitted and accepted for 2017 International Conference on High Voltage and Power System. Another paper is in preparation for possible publication in conference/journal. This research project also enable researchers at UTC to gain knowledge and experience in anomaly detection in distribution network and gain valuable lessons that can be disseminated to other public power utilities in the region and beyond.
Project Web Page(s)	*Please provide the complete URL.* N/A

Quad Chart

Title: Near Real-time Detection of Anomalous Power Consumption in Smart Power Distribution Networks

PI: N. Sisworahardjo, Co-PIs: A. Arabshahi, K. Sreenivas, Graduate Student: Akram Saad

Date: 07/01/2016 – 06/30/2017

Project Concept: • To developed a techique to monitor and detect energy consumption and diagnosing abnormal behavior. • To improve power distribution system resiliency, stability, and to meet energy efficiency targets.	**Operational Capability:** • To enhance the anomaly detection technique with near real-time data visualization. • To enhance the ability to detect early sign of failure of the equipment. • To provide better service to customers by increasing customers energy usage awareness.
Proposed Technical Approach: Literatures review: To gain understanding on various techniques and methodologies to address similar issue. To identify possible techniques which can be enhanced and used concurrently to achieve better results. Data identification and gathering: Determine data type and classification along with duration and choose the sample data. Anomaly detection model development: Enhanced contextual anomaly detection algorithm to detect irregular power consumption. Data Visualization: Visualized anomaly scores using unsupervised learning algorithm and temporal context generated from meter readings.	**Rough Order of Magnitude Cost and Schedule:** 07/16 – 09/16 Review of Literature 08/16 – 04/17 Anomaly detection model development 11/16 – 06/17 Data visualization development Total project: $96,477.00 Deliverables: • Monthly progress reports • Final report • Technical report Contact: N. Sisworahardjo University of Tennessee at Chattanooga EMCS 331A, Dept 2342 615 McCallie Avenue Chattanooga, TN 37403-2598 Phone: (423) 425-5753; Fax: (423) 425-1732

ACCOMPLISHMENTS & OUTCOMES

Project Overview

Provide a scientific / technical overview of your research project – hypothesis or scientific aims, methodologies and activities, outcomes, etc.

Monitoring energy consumption and diagnosing abnormal behavior will enable utilities to introduce strategies to improve system resiliency, stability, and to meet energy efficiency targets. The deployment of advanced metering infrastructure (AMI) enables utilities to collect various raw data from its customers and networks. A contextual anomaly detection algorithm was developed to detect irregular power consumption and visualize anomaly scores using unsupervised learning algorithm and temporal context generated from meter readings. The proposed algorithm computes an anomaly score for each user by considering historical consumption data. The anomaly score for a user is then adjusted by analyzing other contextual variables such as seasonal variation day of the week and other users with the same historical pattern. The implementation on real-world data set provided by power utility company shows a high performance of the proposed algorithm.

List of Objectives / Aims / Major Milestones Proposed	Cumulative Outcomes / Accomplishments
Literatures review	Through extensive review of existing literatures, we gained understanding on various techniques and methodologies to address similar issue. We identify possible techniques which can be enhanced and used concurrently to achieve better results.
Data identification and gathering	Data type and classification along with duration were determined and with EPB counterpart, we successfully obtained real data from EPB.
Anomaly detection model development	Enhanced contextual anomaly detection algorithm to detect irregular power consumption.
Data Visualization	Visualized anomaly scores using unsupervised learning algorithm and temporal context generated from meter readings.
Extend collaboration and research	This is ongoing activities in building network and to exchange ideas with peers and explore possible research collaboration.

Add rows as needed.

Challenges & Strategies Used to Address / Overcome:

Discuss any challenges or barriers that you encountered, particularly if you were impeded from achieving the objectives and milestones approved in your proposal.

Acquiring data from EPB counterpart seems longer than expected which causing delay in testing and refining our methodology. Nevertheless, we able to achived our main objectives.

What didn’t work? What did you disprove or learn from the parts that didn’t meet your initial concept at the proposal?

Describe any areas where you did not meet goals; negative results are important too and should be explained and documented. Mostly, what did you learn besides what you achieved whether it met your expectations at the outset of this effort?

Due to the delay in data gathering, we unable to refine existing demand prediction model using additional weather variables. The failure to perform this task, by no means affecting our effort to achieved the main objectives.

IMPACT & OUTCOMES

Impact on the career(s) of the PI, the co-PIs, and key collaborators	Through this project, our team members (PI and co-PIs) gained tremendous experience in big data and data analytics and understand the possible utilization that not only limited to power industries but also in other diciplines. Strategic relationship with local industry was strengthened with extensive collaboration with EPB and provide us opportunity to further this collaboration in scholarship activities.
Students Impacted	*Please list students including name, brief description of how they were impacted, what degree sought or when graduated, and any other relevant details.* One graduate student participated in this project. Through the project, student gained first-hand experience in research and scholarship activities. Student had opportunity to write technical report which leads to paper(s) publication in conference/journal.

Community and Broader Impacts	*Consider and discuss the technical and actual or potential societal impacts of your research project.* Through this research activity, the finding can have immediate benefits and shared with EPB. EPB will able to implement the proposed technique to improve its ability to detect anomaly power consumption in its network and provide better service to its customers. Other utilities can also gain the benefit from this finding to improve the services for their customers. Therefore the knowledge and experience in anomaly detection in distribution network and gain valuable lessons that can be disseminated to other public power utilities in the region and beyond through further collaborations and conference.
Work products reduced to practice; provide a bibliographical entry where appropriate	*Please include software, papers, presentations, posters, and creative works. Indicate Refereed Journal, Refereed Conference, Non-refereed Conference for each publication listed. For journal publications, indicate the impact factors where appropriate.* One paper was submitted and accepted for 2017 International Conference on High Voltage and Power System. Another paper is in preparation for possible publication in conference/journal.
New inventions reduced to practice and when they will be formally disclosed;	*Please consider and include new software products that are subject to copyright but also methods and systems are potentially patentable. If you filed invention disclosures, patent or copyright applications during the period of performance, please indicate so here as well. If you wish to open source a software prototype data set, please state so; we will follow up with you with a disclosure process and guidance on how to proceed effectively for UTC and our research program, including required steps prior to doing so, and how properly to credit ownership to the UT system.* This research project enable researchers at UTC to gain knowledge and experience in anomaly detection in distribution network and gain valuable lessons that can be disseminated to other public power utilities in the region and beyond.
Outreach & Collaboration	*Please list any visitors, workshops, or other collaborative events did you hold? Indicate the location (on campus, etc.).* Attending NSF sponsored workshop in summer 2017. During this event, we were able and intiate possible collaboration with participants from Tuskegee University, University of the District of Columbia, University of South Alabama, and University of Alabama A&M. Intense communication with other collaborators is ongoing.

EXTERNAL FUNDING

Proposal Submissions	*Please list all sponsored program proposals submitted during the reporting period related to this or previous CEACSE awards.* • National Science Foundation, REU Site: An Interdisciplinary CubeSat Research and STEM Education Platform at the University of Tennessee at Chattanooga (UTChattSat) • National Science Foundation, EXCEL: EXploring Clean Energy through hands-on Learning • Tennessee Department of Transportation (TDOT), Road Health Monitoring System
Contracts / Awards Received	*List any awards or agreements received / executed related to this or previous CEACSE awards. Include sponsor name, sponsor program name (if applicable), project title, and award amount. If it is a non-funding agreement, identify by type (e.g., Data Use Agreement, Non Disclosure Agreement, Material Transfer Agreement, etc.).* Non-Disclosure Agreement between UTC and EPB
Sponsored Program Capacity Building Activities	*List all capacity-building activities in which you have engaged during the award period. Examples may include meeting with a sponsor program officer, attending an NSF/NIH/other sponsor regional workshop, participating in GWSW activities, attending on-campus workshops, etc.* Attending workshop/conference: • NSF Workshop, June 16-17, 2017, University of Minnesota, Minneapolis, Minnesota. • 8th Indonesia Focus Conference, University of Kentucky, Lexington, Kentucky, September 30 - October 1, 2016

WHAT'S NEXT FOR THIS RESEARCH?

How will you follow up your CEACSE grant with work in the next 1,2, … 5 years?	During the duration of the grant, we successfully build collaborative network with researchers from different institutions and industries. As for for immediate plan, we are planning to have joint authorship to be presented in conferences and/or journals. Meanwhile, we will try to explore possible research collaboration.

What other related research will you pursue (and with whom) in light of the support you've received from CEACSE?	We will further and continue our research work by refining and adding the layer of complexity on our technique and broaden research exploration on big data analytics in power distribution. We will work with our partner from industries (EPB/TVA) and along with other researchers in the US and abroad (New Zealand and Indonesia)
Tell us anything else we should know about this work not described above.	With capability of power utility to gain access of data from its network and customers, will open excellent opportunity to analyze the data and able to present it in the maningful way to various level of interest intities. Therefore, gaining the expertize in this area not only will strengthen our position in this area but the lesson learned from it can be used for other aspect or areas such as in transportation, city, healtcare, and others.
What barriers (if any) do you face to reach these next goals?	• Although the internet allows us to communicate, face-to-face meeting with peers and partners is not that less important. Travel funding support to meet and/or attend professional meeting with other researchers is pivotal. • Hiring the high quality of graduate students with finanacial support (scholarship as RA/TA) . Therefore ability to offer scholarship to the potential graduate students is extremely important to attract bright students to our campus.

FINANCIAL ACCOUNTING

Financial Report:	**Total Award Amount:**	$96,477.00
	Cumulative Expenditures:	$85,588.06
	Remaining Award Amount:	$10,888.94

Please attach the following:

- *Final ledger report showing the final accounting for your award.*
- *Line item budget spreadsheet comparing your original, approved budget to how funds were actually expended.*
- *Updated budget narrative describing how funds were expended and how expense contributed to the achievement of project goals, objectives, and milestones.*

Supplemental Award Request	*Have you or do you anticipate applying for a supplemental award for any portion of the remaining balance? If so, please include the amount requested (or planned).*	$1,308.00

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CUMULATIVE FINAL REPORT
(Submit as a Microsoft Word document [not PDF] via e-mail to Tony-Skjellum@utc.edu with a copy to Joanne-Romagni@utc.edu)

PROJECT OVERVIEW

Lead PI	*Kidambi Sreenivas, PhD*
Co-PI(s)	*Abi Arabshahi, PhD, Robert Webster, PhD*
Other Personnel	
Project Title	**Towards simulation of vertical axis wind turbines in offshore settings**
Date Submitted	03/07/2016
Award Start - End Date	07-01-2016 through 06/30/2017
Non-Technical Summary – 500 words or less	The objectives of this project were to take first steps towards the numerical simulation of the flow field surrounding vertical axis wind turbines (VAWT) in offshore settings. This work was carried out in collaboration with Sandia National Laboratory, with Dr. Todd Griffith as the POC. The idea behind the project was to carry out initial validation using data from a VAWT that Sandia had tested in the 70s and 80s. These experiments were carried out onshore and once this validation was completed, a future project (potentially funded through Sandia National Lab/DOE) would have involved transitioning the VAWT to an offshore setting. Almost all commercial wind turbines are three-bladed and of the horizontal axis variety. Consequently, there isn't a large body of research supporting VAWTs. This became abundantly clear as we looked for detailed geometry for the Sandia VAWT. The first roadblock we ran into was that proprietary airfoil sections were used in the Sandia VAWT. After significant back and forth between the PIs and Dr. Griffith, we were able to obtain the geometry of these airfoil sections. The second roadblock was that these wind turbines were built and tested in the era of "pencil and paper", i.e., there were no solid models (CAD) available that defined this geometry. Based on various reports we found (some were provided by Dr. Griffith), we reconstructed the geometry as best as we could. Even with this effort, these were significant doubts about the geometry definition and there was no way to verify the same as the test article does not exist anymore. Simulations were carried out based on the geometry we had created, but the results were not satisfactory. Consequently, attempts to get some of these results published were unsuccessful. Given that the simulations of the Sandia VAWT provided less than satisfactory results, we began the search for relatively recent experimental data, which had the added advantage of having well defined geometry. This search clearly showed us the paucity of experimental data for VAWTs. The only experimental dataset that could be found was completely fortuitous as the PI happened to be at a talk at the AIAA Aviation Conference in Denver (June 2017) where they discussed some of the results. The results were focused on details of the flow field as opposed to the power produced by the VAWT. Additional searches after the conference turned up one more dataset that could be of use. After returning from the conference, the geometry was created and simulations have been carried out. However, there was not enough time between the end of the conference and the end date of the project in order to carry out a thorough validation of the flow field. The PIs will continue these simulations over the course of the fall and spring semesters (as time permits) to see if good agreement with experimental data can be obtained. This project, while not very successful, initiated collaboration between the SimCenter and Sandia National Lab. Additionally, it supported the SimCenter's swimming lane related to "Energy & Environment". The future for this kind of alternate energy research is uncertain because of the changes in the political climate at the federal level.

ACCOMPLISHMENTS & OUTCOMES

Project Overview

Provide a scientific / technical overview of your research project – hypothesis or scientific aims, methodologies and activities, outcomes, etc.

The main technical objective was to carry out simulations of the Sandia 34m Vertical Axis Wind Turbine (VAWT) and compare to experimental data. The approach involved using Tenasi, a node-centered, finite-volume, unstructured flow solver in order to simulate the flow field associated with this turbine and derive associated performance characteristics from the computed flow field for comparison to experimental data. Tenasi had been successfully used for simulations of various Horizontal Axis Wind Turbine configurations (single, tandem, offset), so it was felt that the flow solver was capable of carrying out simulations of VAWTs.

One of the most important aspects of any flow simulation is geometric fidelity, i.e., the quality and accuracy of the underlying geometry. If this geometry is of high quality and care has been taken in handling it correctly during the grid generation phase, the simulated flow field will also be of correspondingly high fidelity. When this project was proposed, it was expected that the geometry of the Sandia VAWT would be available at some reasonable level of fidelity and that our collaborator, Dr. Todd Griffith, would be able to procure the same for us. It turned out that this was not quite the case. The biggest problems we ran into were the definition of the airfoil sections that made up the blades, uncertainty over how exactly they were oriented to form the blade, and how transitions between various sections of the blade were carried out. The first problem was reasonably resolved after a lot of back and forth with Dr. Griffith as he had to go into the archives in order to be able to discover/find the airfoil coordinates for the proprietary sections that were used in the design of this VAWT. Even with this data, the level of fidelity was limited as the airfoil section was defined with only a 100 or so points for the entire surface (typical definitions involve either analytical curves or resolutions of 1000 points or so). Once we had the geometry of the airfoils, the next step was to stack them such that the blade geometry could be obtained. This step proved to be an insurmountable obstacle as all we had to work with were reports' dating back to the 1970s as that was the time frame when these experiments were carried out. These reports provided some detail as to how the blades could be constructed, however, they were not written with the expectation that it would be used for high-fidelity numerical simulations 50 years after the fact. Consequently, guesses had to be made regarding how these airfoils were stacked and this resulted in a lot of uncertainty in the final geometry. Furthermore, the blades were built in sections and the transitions between these sections were ad-hoc, to put it mildly. There was nothing that Dr. Griffith could do to help with these issues as the people who had worked on this project have long since retired and the test article itself had been decommissioned.

If these factors had come to light early in the project, we could have possibly changed tacks and looked for other experimental data. However, each of these iterations was a month's long exercise and by the time we came to the realization that the geometry was not going to be available at the expected level of fidelity, it was already April 2017. At this point, we scrambled to look for other experimental data so that we could still bring this project to a successful completion. However, it turned out that not much work had been done on VAWTs beyond what was done in the 1970s. The reason for that was the commercial companies had spent a lot of resources on HAWTs and most of the experiments were designed to understand the flow fields associated with HAWTs better. Only recently have experiments been done with an eye on generating high-fidelity data which can be used for CFD validation. The existence of this data was a chance discovery when the PI attended a talk at the AIAA Aviation Forum in June 2017 where it was discussed. Unfortunately, this came very late in the game to be of use during the project period. Since then, one other source of experimental data (related to VAWTs) has been identified and both of these sources appear to have high quality data together with high-fidelity geometry.

While the objectives of this project were not accomplished during the period of the award, the PIs expect to continue working on this with the newly available geometry and data and hope to reengage with Sandia Labs once some results are available.

List of Objectives / Aims / Major Milestones Proposed	Cumulative Outcomes / Accomplishments
Coordinate with Dr. Griffith (Sandia Labs) in order to obtain geometry and experimental data for the Sandia VAWT	The coordination was successful in obtaining the experimental data for the Sandia VAWT. However, getting the geometry proved to be very challenging because the personnel associated with the project had long since retired and the test article in question is no longer in existence. Furthermore, the geometry was not available in a CAD format and there was a lot of uncertainty about the transition sections between the airfoils.

Submit conference papers	Extended abstracts were submitted to the AIAA Wind Energy Symposium; however, the uncertainty in geometry and the unsatisfactory results did not result in acceptance of the paper.
Submit joint proposals for extramural funding	Given the unsatisfactory results, joint proposals were not pursued. If the simulations utilizing the new geometries (corresponding to new test cases that have well defined geometry) show promising results, the topic of joint proposals will be revisited.

Challenges & Strategies Used to Address / Overcome:
The biggest challenge in this project was the availability of geometry for the Sandia VAWT. Going into the project, it was anticipated that the geometry was the one thing that would be easily available. However, that turned out to be the biggest challenge. We attempted to overcome the challenge by coordinating with Dr. Griffith at Sandia Labs. The first setback was the airfoil section used in the VAWT. This was a proprietary section that was not available in the open literature. After much searching, Dr. Griffith was able to obtain the coordinates for us. Unfortunately, this cross section was defined very sparsely resulting in a poor representation of the airfoil. We decided to proceed with this airfoil as higher fidelity geometry was not available. Then we ran into the problem with the transition section between sections of the blade where different airfoils were used. These transition sections were not defined in any of the reports. Some of them indicated that a sleeve was used to cover the transitions, however, no drawings or descriptions of the sleeve were available. The bottom line was that the quality of the geometry was poor and this was reflected in the unsatisfactory agreement obtained with experimental data.

What didn't work? What did you disprove or learn from the parts that didn't meet your initial concept at the proposal?
There is an old dictum in CFD: Boundary conditions are the problem. In our case, the boundary conditions are provided by the geometry of the wind turbine. In earlier successful simulations (of horizontal axis wind turbines), we had geometry available as IGES (Solid models) files. That was not true in this case. We had to create the geometry and even then, significant pieces of it were ill-defined. We proved that geometry is king and without an accurate representation of the test article, even the most sophisticated flow solver will not be very successful in comparing favorably to experimental data.

IMPACT & OUTCOMES

Impact on the career(s) of the PI, the co-PIs, and key collaborators	None, at this stage. This can change as we carry out simulations of the new geometry.
Students Impacted	*Please list students including name, brief description of how they were impacted, what degree sought or when graduated, and any other relevant details.* David Collao: David was responsible for creating the geometry and generating the meshes for this project. He became comfortable with using the CAD tools within Pointwise to create geometry as a result of this project. He has since graduated with a PhD in Computational Engineering (2017) and is currently employed by a local company that creates software for 3D modeling for dentures and other dental implants.
Community and Broader Impacts	*Consider and discuss the technical and actual or potential societal impacts of your research project.* None at this stage. Further simulations based on better quality geometry could change that.
Work products reduced to practice; provide a bibliographical entry where appropriate	*Please include software, papers, presentations, posters, and creative works. Indicate Refereed Journal, Refereed Conference, Non-refereed Conference for each publication listed. For journal publications, indicate the impact factors where appropriate.* None
New inventions reduced to practice and when they will be formally disclosed;	*Please consider and include new software products that are subject to copyright but also methods and systems are potentially patentable. If you filed invention disclosures, patent or copyright applications during the period of performance, please indicate so here as well. If you wish to open source a software prototype data set, please state so; we will follow up with you with a disclosure process and guidance on how to proceed effectively for UTC and our research program, including required steps prior to doing so, and how properly to credit ownership to the UT system.* None

Outreach & Collaboration	*Please list any visitors, workshops, or other collaborative events did you hold? Indicate the location (on campus, etc.).* Collaborated with Dr. Todd Griffith, Sandia National Laboratory. All of the interaction was through email and phone calls.

EXTERNAL FUNDING

Proposal Submissions	*Please list all sponsored program proposals submitted during the reporting period related to this or previous CEACSE awards.* None related to this project. Related to other CEACSE awards: Heterogeneous HPC for High-order Stabilized Finite-elements on Moving and Deforming Domains, HPCMP, $400K
Contracts / Awards Received	*List any awards or agreements received / executed related to this or previous CEACSE awards. Include sponsor name, sponsor program name (if applicable), project title, and award amount. If it is a non-funding agreement, identify by type (e.g., Data Use Agreement, Non Disclosure Agreement, Material Transfer Agreement, etc.).* Heterogeneous HPC for High-order Stabilized Finite-elements on Moving and Deforming Domains, HPCMP, $400K
Sponsored Program Capacity Building Activities	*List all capacity-building activities in which you have engaged during the award period. Examples may include meeting with a sponsor program officer, attending an NSF/NIH/other sponsor regional workshop, participating in GWSW activities, attending on-campus workshops, etc.* Met with Dr. Mike List and colleagues at AFRL, Wright Patterson AFB, Dayton, OH Met with Drs. Hua Shan, Chandra Kannepalli, and Matthew Jemison at NSWC-Carderock Division, Washington, DC Met with researchers from SmartTruck (at the SimCenter). SmartTruck is a company that designs and produces after-market drag reduction devices for Class 8 trailers Talked to Jared Luebe of Kewit Engineering Group. They were interested in us carrying out some simulations for an LNG project they were looking to work on, though the LNG project fell through.

WHAT'S NEXT FOR THIS RESEARCH?

How will you follow up your CEACSE grant with work in the next 1,2, … 5 years?	Work will continue on carrying out simulations of vertical axis wind turbines (as time permits) over the next year. If good results are obtained, efforts will be made to secure external funding for the same.
What other related research will you pursue (and with whom) in light of the support you've received from CEACSE?	Research is underway on porting FUNSAFE, a finite-element flow solver, to heterogeneous architectures. FUNSAFE can be used for the simulations of vertical axis wind turbines, once the geometry issues have been resolved.
Tell us anything else we should know about this work not described above.	
What barriers (if any) do you face to reach these next goals?	None at this stage

FINANCIAL ACCOUNTING

Financial Report:	**Total Award Amount:**	$96,573.00
	Cumulative Expenditures:	$92,095.20
	Remaining Award Amount:	$ 4,477.80

Please attach the following:

- *Final ledger report showing the final accounting for your award.*
- *Line item budget spreadsheet comparing your original, approved budget to how funds were actually expended.*
- *Updated budget narrative describing how funds were expended and how expense contributed to the achievement of project goals, objectives, and milestones.*

Supplemental Award Request	*Have you or do you anticipate applying for a supplemental award for any portion of the remaining balance? If so, please include the amount requested (or planned).* No	$

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CUMULATIVE FINAL REPORT

(Submit as a Microsoft Word document [not PDF] via e-mail to Tony-Skjellum@utc.edu with a copy to Joanne-Romagni@utc.edu)

PROJECT OVERVIEW

Lead PI	Craig Tanis, PhD
Co-PI(s)	Kidambi Sreenivas, PhD
Other Personnel	None
Project Title	Optimizing FUNSAFE for Leadership-Class Machines
Date Submitted	June 2016
Award Start - End Date	July 1 2016 – July 31 2017
Non-Technical Summary – 500 words or less	The goal of this project was to update the SimCenter-developed finite element code, FUNSAFE, optimizing it for GPU-enabled supercomputing systems, and getting a large case to run on the Titan system at Oak Ridge National Lab. Over the course of the project, we switched to focusing on the SimCenter's new GPU-based system. Impressive performance results for parts of FUNSAFE were achieved, but the full port is incomplete. We (Dr. Tanis as Co-PI) have been awarded external funding to continue this work, including an update of the code to use the Kokkos framework for performance portability.
Project Web Page(s)	None

Please attach a Quad Chart using the following format as an example:
http://www.usamraa.army.mil/pages/baa_paa/fy06quaddirections_jsto_baa.pdf.

ACCOMPLISHMENTS & OUTCOMES

Project Overview

The objective of this project was to modify UTC's **FUNSAFE** computational simulation framework to perform optimally on leadership-class supercomputers, and to demonstrate FUNSAFE capabilities at scale on the Titan system at ORNL.

FUNSAFE is a modular Fortran code supporting a range of multi-physics simulations, including high-order compressible/incompressible fluid dynamics, frequency and time-domain electromagnetics, Li-Ion batteries and structural mechanics. One of the particular strengths of FUNSAFE is the way that new modules may be implemented without impacting the others. Because of this, application scientists can develop new physics models without understanding the nuances of performant parallel programming. It was desirable to improve FUNSAFE's heterogeneous performance without requiring application scientists to worry about computational accelerators.

We saw many opportunities to improve FUNSAFE performance and improve the separation between application science and computer science in the new implementation by changing the codebase to use C++ templates. This transition was unplanned during the grant submission process and drastically affected our timeline. In retrospect this was a necessary move, because the original Fortran implementation was inherently limited in performance-related matters.

During the migration to C++, we began using Dr. Tanis's Splatter package for parallel mesh management, and enabled the use of PETSc linear solvers. New C++ templates were developed to allow application scientists to write code with respect to individual Gauss points for arbitrary elements. The system became responsible for dispatching these templated kernels on the appropriate hardware.

We've demonstrated extremely fast numerical integration over Gauss points with a simple element volume kernel. At this point we became aware of the Kokkos project and began planning to integrate that in our templates, for improved performance portability. This is part of the work proposed and awarded in the PETTT project listed below.

List of Objectives / Aims / Major Milestones Proposed	Cumulative Outcomes / Accomplishments
Update of FUNSAFE for GPU accelerators	Developed new accelerator-aware routines for finite element simulations on accelerator hardware.
Development of flagship simulation	Increased local knowledge on performance portability issues and accelerator-based system architectures.
Awarded time on Titan system at ORNL	Great preliminary performance results on new SimCenter machine.
	Awarded external funding for additional related work.

Add rows as needed.

Challenges & Strategies Used to Address / Overcome:
This project transformed from being a straightforward Fortran optimization project to one that involved a more intensive port to C++. The extra time required for this work led to modified project goals and outcomes, including the desire to initially target the SimCenter's new GPU cluster. Ultimately this was time well spent, as it laid the groundwork for more FUNSAFE capabilities going forward, including performance portability.

What didn't work? What did you disprove or learn from the parts that didn't meet your initial concept at the proposal?
As described above, the project simply became more time-intensive than initially expected. I've learned to build more time for research and experimentation into my proposed project timelines.

IMPACT & OUTCOMES

Impact on the career(s) of the PI, the co-PIs, and key collaborators	Tanis (PI): this project enabled me to spend much extra time focusing on research, and better understand the demands of sponsored projects. This will undoubtedly help me better plan and spend my time going forward, so that more reasonable expectations may be set.
Students Impacted	Dominique Pennington, graduated undergrad May 2017, was quite helpful in studying the differences between Xeon Phi and NVIDIA GPU hardware. He was sent to a supercomputing symposium at Oklahoma State in support of this work. This work manifested itself distinctly in Dr. Tanis Spring 2017 graduate course offering on Parallel Algorithms, particularly with respect to GPU programming.
Community and Broader Impacts	UTC's collective understanding of modern heterogeneous system architectures has been improved.
Work products reduced to practice; provide a bibliographical entry where appropriate	Pending
New inventions reduced to practice and when they will be formally disclosed;	Pending

Outreach & Collaboration	This project further strengthened collaboration between the SimCenter and Computer Science and Engineering departments at UTC.

EXTERNAL FUNDING

Proposal Submissions	CEACSE 2017-18 “Expanding FUNSAFE capability” (not awarded) PETTT “Heterogeneous HPC for High-order Stabilized Finite-elements on Moving and Deforming Domains” (Drs. Tanis and Sreenivas as Co-PI)
Contracts / Awards Received	PETTT “Heterogeneous HPC for High-order Stabilized Finite-elements on Moving and Deforming Domains” (Drs. Tanis and Sreenivas as Co-PI); Engility Corp. Funded for approximately $422,000 over two years.
Sponsored Program Capacity Building Activities	Tanis conference attendances: Supercomputing 2016 (Workshop on heterogeneous computing) PEARC 2017 (part of Regional Campus Champion leadership).

WHAT’S NEXT FOR THIS RESEARCH?

How will you follow up your CEACSE grant with work in the next 1,2, … 5 years?	The immediate goal is to fulfill the responsibilities of the awarded external funding (PETTT). This will lead to additional FUNSAFE capabilities spanning the gamut of applications.
What other related research will you pursue (and with whom) in light of the support you've received from CEACSE?	Potential collaboration with NASA, others. (hearsay). This work continues to be of vital interest to the SimCenter, and there are many paths forward.
Tell us anything else we should know about this work not described above.	
What barriers (if any) do you face to reach these next goals?	Time.

FINANCIAL ACCOUNTING

Financial Report:	**Total Award Amount:**	$86,741
	Cumulative Expenditures:	$69,935
	Remaining Award Amount:	$16,806

Please attach the following:

- *Final ledger report showing the final accounting for your award.*
- *Line item budget spreadsheet comparing your original, approved budget to how funds were actually expended.*
- *Updated budget narrative describing how funds were expended and how expense contributed to the achievement of project goals, objectives, and milestones.*

Supplemental Award Request	Yes	$8,247

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CUMULATIVE FINAL REPORT

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PROJECT OVERVIEW

Lead PI	*List personnel as you would like for them to appear in a formal report – e.g., Dr. John Smith / John Smith, PhD, etc.* Dr. Robert Webster
Co-PI(s)	None
Other Personnel	*Identify by type – senior personnel, technicians, graduate students, undergraduate students* Drs. Kidambi Sreenivas and Ethan Hereth; Mr. David Collao
Project Title	Numerical Simulations of Axial Compressor Flow Fields Employing Higher-order Accuracy
Date Submitted	30 August, 2017
Award Start - End Date	1 July, 2016 – 30 June, 2017
Non-Technical Summary – 500 words or less	*Please provide a non-technical summary of your project that addresses the major objectives, accomplishments, and outcomes of your project. Discuss impacts of the project in terms of scholarly contributions to the field, scholarly outputs, student and community impacts, etc. Address how your project advanced or supported the mission of the SimCenter.* The major objective was to make use of higher-order spatial accuracy in the simulations of an axial compressor, for which there was a reasonable experience base using standard (i.e., 2nd order) spatial accuracy. Thus, one-to-one comparisons could be made, especially with regard to comparison of the numerical results with experimental results in terms of overall performance parameters. The original plan was to use both finite-volume and finite-element methodologies with higher-order spatial accuracy and make comparisons between the two methodologies, as well as with experiment. In the end, only the finite-volume methodology was tested, since it was “ready to use”, at least as applied to rotating machinery. Even so, this was a useful experience as it provided clear evidence that the use of higher-order spatial accuracy improved the agreement with experiment.
Project Web Page(s)	*Please provide the complete URL.* None.

ACCOMPLISHMENTS & OUTCOMES

Project Overview

Provide a scientific / technical overview of your research project – hypothesis or scientific aims, methodologies and activities, outcomes, etc.

As mentioned earlier, the major objective was to employ higher-order spatial accuracy to numerical simulations of a multi-stage, axial-flow compressor. Earlier simulations using standard 2^{nd}-order accuracy compared well to experiment at low- to nominal-loading conditions in terms of overall and stage performance (measured as total pressure ratio as a function of corrected mass flow rate). At high-loading conditions, the use of 2^{nd}-order accuracy over-predicted the performance, again in the sense of overall and stage performance. A relatively ad hoc methodology was then used in a finite-volume formulation to increase the spatial accuracy where possible. This had been shown to improve simulation agreement when applied to wind turbine flow fields, but this effort was the first time to try higher-order accuracy for a more complicated axial-flow compressor. The results improved at the high-loading conditions, and this is felt to be due to the fact that wake losses were more accurately captured, thus bringing the computed performance more in line with experiment at these conditions. There was little, if any, change in the low- to nominal-loading numerical results, since the influence of wake losses would not be as great at these operating conditions. The intent was also to a use high-order finite element methodology, but that required some code development efforts that were not fully accomplished during this time period. However, a newly awarded grant will allow that effort to be brought to fruition.

List of Objectives / Aims / Major Milestones Proposed	Cumulative Outcomes / Accomplishments
Exploring higher-order spatial accuracy using finite-volume methodology of Weighted Essentially Non-Oscillatory (WENO) flux formulations	The use of this methodology made a noticeable improvement in the accuracy of simulations performed on a multi-stage axial compressor.
Use of high-order finite-element analysis (FEA) in rotating machinery flows	This objective was not realized during the course of this project, since the development was not fully implemented and tested.
Conducting numerical simulations using both WENO and FEA on axial compressor	The WENO methodology was extensively tested; FEA was not for the reason/outcome noted above.
Comparing WENO and FEA to each other and experiment	Comparisons were not made between the two methodologies for the reason/outcome of the second objective.

Add rows as needed.

Challenges & Strategies Used to Address / Overcome:

Discuss any challenges or barriers that you encountered, particularly if you were impeded from achieving the objectives and milestones approved in your proposal.

As stated above, the second objective was not met. This was due largely to an underestimation of what was required for the development effort. Progress was made toward this goal, but it was not fully completed. Milestones are estimations, and sometimes not all milestones are met to the degree anticipated; this is not necessarily uncommon in research. Even though the second objective was not met, the overall goal of investigating the impact of higher-order spatial accuracy was met.

What didn't work? What did you disprove or learn from the parts that didn't meet your initial concept at the proposal?

Describe any areas where you did not meet goals; negative results are important too and should be explained and documented. Mostly, what did you learn besides what you achieved whether it met your expectations at the outset of this effort?

See above.

IMPACT & OUTCOMES

Impact on the career(s) of the PI, the co-PIs, and key collaborators	This work, in addition to similar efforts from previous years, has led to a PETTT grant award that the PI and fellow colleagues will be involved with. This is a source of external funding that should be useful in aiding the PI as he works toward attaining tenure.
Students Impacted	*Please list students including name, brief description of how they were impacted, what degree sought or when graduated, and any other relevant details.* None.

Community and Broader Impacts	*Consider and discuss the technical and actual or potential societal impacts of your research project.* Increased accuracy of computational simulations of axial compressor flows, in conjunction with experimental efforts, should in the long run lead to a better understanding of the flow physics, which can aid in design improvements. These improvements should then lead to increased performance, operability and thermodynamic efficiency of gas turbine engines for both aircraft propulsion and ground-based power plants.
Work products reduced to practice; provide a bibliographical entry where appropriate	*Please include software, papers, presentations, posters, and creative works. Indicate Refereed Journal, Refereed Conference, Non-refereed Conference for each publication listed. For journal publications, indicate the impact factors where appropriate.* Sreenivas, K., Webster, R.S., and Hereth, E.A., "Impact of High-Order Spatial Accuracy on Multi-Stage Turbomachinery Simulations," AIAA-2017-4823, 53rd AIAA/SAE/ASEE Joint Propulsion Conference, 10 – 12 July, 2017, Atlanta, GA.
New inventions reduced to practice and when they will be formally disclosed;	*Please consider and include new software products that are subject to copyright but also methods and systems are potentially patentable. If you filed invention disclosures, patent or copyright applications during the period of performance, please indicate so here as well. If you wish to open source a software prototype data set, please state so; we will follow up with you with a disclosure process and guidance on how to proceed effectively for UTC and our research program, including required steps prior to doing so, and how properly to credit ownership to the UT system.* None.
Outreach & Collaboration	*Please list any visitors, workshops, or other collaborative events did you hold? Indicate the location (on campus, etc.).* Participation in the Research Dialogues program held on campus in April, 2017.

EXTERNAL FUNDING

Proposal Submissions	*Please list all sponsored program proposals submitted during the reporting period related to this or previous CEACSE awards.* "Heterogeneous HPC for High-order Stabilized Finite-elements on Moving and Deforming Domains." The proposal was for $422,001 (over two years) from the Engility Corporation.

Contracts / Awards Received	*List any awards or agreements received / executed related to this or previous CEACSE awards. Include sponsor name, sponsor program name (if applicable), project title, and award amount. If it is a non-funding agreement, identify by type (e.g., Data Use Agreement, Non Disclosure Agreement, Material Transfer Agreement, etc.).* See above.
Sponsored Program Capacity Building Activities	*List all capacity-building activities in which you have engaged during the award period. Examples may include meeting with a sponsor program officer, attending an NSF/NIH/other sponsor regional workshop, participating in GWSW activities, attending on-campus workshops, etc.* The PI and colleague (Dr. Kidambi Sreenivas) met with Dr. Michael List, director of the compressor research facility at Wright-Patterson Air Force Base. This occurred in September, 2016. A portion of that meeting was related to this project and was likely helpful in being considered for the grant that was awarded. Also, the presentation of the conference paper listed above has sparked a renewed interest from personnel at the NASA Glenn Research Center.

WHAT'S NEXT FOR THIS RESEARCH?

How will you follow up your CEACSE grant with work in the next 1,2, … 5 years?	Obviously, the most immediate follow-up will be working on the grant that has been recently awarded. It is also planned to work toward rebuilding the working relationship with NASA-Glenn that has stagnated somewhat over the last two to three years. Perhaps this can lead to additional research funding from NASA-Glenn, which is heavily involved in research involving flow fields with rotating machinery.
What other related research will you pursue (and with whom) in light of the support you've received from CEACSE?	Higher-order spatial accuracy would aid in the simulations of most anything related to aerospace propulsion. The PI and colleagues are hoping to collaborate with researchers at Auburn University in the application area of combustion instability. The computation of the acoustic "component" of combustion instability should benefit greatly from the use of higher-order spatial accuracy. This could be applicable to both gas-turbine and rocket propulsion.

Tell us anything else we should know about this work not described above.	
What barriers (if any) do you face to reach these next goals?	

FINANCIAL ACCOUNTING

Financial Report:	**Total Award Amount:**	$
	Cumulative Expenditures:	$
	Remaining Award Amount:	$

Please attach the following:

- *Final ledger report showing the final accounting for your award.*
- *Line item budget spreadsheet comparing your original, approved budget to how funds were actually expended.*
- *Updated budget narrative describing how funds were expended and how expense contributed to the achievement of project goals, objectives, and milestones.*

Supplemental Award Request	*Have you or do you anticipate applying for a supplemental award for any portion of the remaining balance? If so, please include the amount requested (or planned).* No.	$

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Center for Excellence in Applied Computational Science & Engineering

CUMULATIVE FINAL REPORT

(Submit as a Microsoft Word document [not PDF] via e-mail to Tony-Skjellum@utc.edu with a copy to Joanne-Romagni@utc.edu)

PROJECT OVERVIEW

Lead PI	*List personnel as you would like for them to appear in a formal report – e.g., Dr. John Smith / John Smith, PhD, etc.* Dr. Dalei Wu
Co-PI(s)	Dr. Yu Liang, Dr. Li Yang, Dr. Farah Kandah, Dr. Joseph M. Kizza
Other Personnel	*Identify by type – senior personnel, technicians, graduate students, undergraduate students* **Graduate students**: Mehran Ghafari, Maxwell Omwenga, Stuart Eudaly, Nada Alharbi, Sharmila chackrawathy, Maha Almaimani, Rabhu Bajracharya **Undergraduate students**: Robert Slaughter, Dakila Ledesma, Christopher Davis, Alaykumar Patel, Suhail Arora, Austin Obyrne, Peter Zeglen, Derek Snyder, Morgan Sanborn, Izabella Arredondo
Project Title	Multiscale Serviceability Analysis and Assessment of Urban Infrastructure
Date Submitted	08/30/2017
Award Start - End Date	07/01/2016 – 06/30/2017
Non-Technical Summary – 500 words or less	*Please provide a non-technical summary of your project that addresses the major objectives, accomplishments, and outcomes of your project. Discuss impacts of the project in terms of scholarly contributions to the field, scholarly outputs, student and community impacts, etc. Address how your project advanced or supported the mission of the SimCenter.* The project was primarily targeted at developing a new multi-scale structural health monitoring system over Big-Data platform (MS-SHM-BD) to monitor and evaluate the serviceability of large-scale civil structures. Under the sponsorship of CEACSE funding, the team has been able to complete the major research goals and tasks of the project. The impacts are: • Two research seminars on the project were given in SimCenter seminar series by the team faculty in early 2017. Research findings were also presented during UTC Research Dialogues 2017. • Total 7 graduate students (3 females) and 10 undergraduate students (2 females) have been involved in the project. • Four research papers have been published, including one book chapter, two journal papers, and one conference paper. A female graduate student is the first author of the conference paper. In addition, two conference papers have been submitted, and two journal papers are under preparation by the team. • The team has submitted four research proposals to NSF, NIST, and NIHS, with one proposal being funded by NSF (#1647175, $299,884).

	• Collaborations have been established with researchers from inside and outside UTC. The team submitted research proposals by collaborating with professors and researchers from University of Vermont, University of Cincinnati, University of Tennessee at Knoxville, Old Dominion University, Oak Ridge National Laboratory, and UTC Math Department. • With the help of The Enterprise Center, The team also held meetings with officials and engineers from local organizations, including Tennessee American Water, EPB, Chattanooga Department of Transportation, and Chattanooga Public Works, for experiment planning and demonstration.
Project Web Page(s)	*Please provide the complete URL.*

Please attach a Quad Chart using the following format as an example:
http://www.usamraa.army.mil/pages/baa_paa/fy06quaddirections_jsto_baa.pdf.

ACCOMPLISHMENTS & OUTCOMES

Project Overview
Provide a scientific / technical overview of your research project – hypothesis or scientific aims, methodologies and activities, outcomes, etc. The objective of the project was to develop a multi-scale structural health monitoring system over Big-Data platform to monitor and evaluate the serviceability of large-scale civil structures. Aiming to evaluate the structural health status of bridges and pipelines, a nationwide bridge/pipeline database survey, global structural integrity analysis, and component structural reliability analysis were performed by using methodologies of machine learning, signal processing, structural modeling and simulation, fatigue analysis, and Bayesian network. Specifically, the following research activities have been carried out. 1) Hadoop enabled data storage and analytics were explored. 2) Machine learning methods were studied for global structural integrity analysis and structural component reliability analysis. 3) Wireless networking (SDN) architecture was investigated for urban infrastructure monitoring and data delivery. The fundamental results of this project could help develop transformative techniques that can lead to improved safety and performance of the nation's urban infrastructure. Research findings were published in one book chapter, two journal papers, and one conference paper. Four grant proposals were submitted to NSF, NIST, and NIHS for external funding applications. One NSF award has been received: NSF (#1647175) "US Ignite: Collaborative Research: Focus Area 1: Fiber Network for Mapping, Monitoring and Managing Underground Urban Infrastructure," $299,884, 01/2017 - 12/2019.

List of Objectives / Aims / Major Milestones Proposed	Cumulative Outcomes / Accomplishments
With data acquisition, transmission and integration, bridges/pipelines database survey will be done to obtain a preliminary characterization of the safety level of major bridges and pipelines in the United States.	A Hadoop platform based on the CS cluster "Qbert" at the SimCenter has been used for data storage and analytics. A software-defined network (SDN) architecture has been proposed for delivery of urban infrastructure monitoring information. Various data analytics techniques such as missing data handling, variable transformation, data management optimization, and dimensionality reduction, etc. were employed.
Based on signal processing techniques, global structural integrity analysis of the targeted bridges/pipelines will be done to characterize and zone the potential damages.	A method for global structural integrity analysis has been developed by using measured structural resonance frequency and computed natural frequency. Ground penetrating radar (GPR) image processing techniques have been explored.
Localized structural component reliability analysis will be done to obtain a precise description about the specific heavily damaged zones/sections.	Two strategies of component reliability analysis, structural reliability analysis and observation-oriented method, have been investigated.
Component reliability analysis results will be synthesized to achieve a holistic characterization of the serviceability of the target bridges/pipelines.	Bayesian network was applied to generate a compact representation of joint probability distributions as global bridges reliability analysis.

Add rows as needed.

Challenges & Strategies Used to Address / Overcome:

Discuss any challenges or barriers that you encountered, particularly if you were impeded from achieving the objectives and milestones approved in your proposal.

- Proper data for global structural integrity analysis targeted bridges/pipelines were missing. To overcome this challenge, collaboration with researchers from the University of Vermont was pursued to collect the needed data (e.g., GPR images).
- Students involved in this project lacked for background knowledge of infrastructure sensing, structural modeling and dynamics theory. Also, it was time-consuming for the team to figure out and get familiar with proper software tools for data processing and visualization. To overcome these issues, the PI and Co-PIs conducted training, provided study materials, and interacted with technicians to help students move forward with the project.

What didn't work? What did you disprove or learn from the parts that didn't meet your initial concept at the proposal?

Describe any areas where you did not meet goals; negative results are important too and should be explained and documented. Mostly, what did you learn besides what you achieved whether it met your expectations at the outset of this effort?

The research topic of this project is broad. At the outset of the project, it was expected to develop novel deep learning algorithms for nationwide bridges/pipelines database survey and component reliability analysis. Also it was expected to construct Bayesian network for integrity analysis. The team has formulated the idea of how to conduct research and then developed some preliminary framework. However, due to the high complexity of those research issues, the team did not meet the original goals in that area. What the team has learned is that the research of the project should have been conducted in a more focused way.

IMPACT & OUTCOMES

Impact on the career(s) of the PI, the co-PIs, and key collaborators	PI: Dr. Dalei Wu, Assistant Professor in Computer Science. Co-PI: Dr. Yu Liang, Associate Professor in Computer Science; Dr. Yang Li, Professor in Computer Science, Dr. Farah Kandah, Assistant Professor in Computer Science, Dr. Joseph Kizza, Professor and Head of Computer Science. Key collaborators: Dr. Dryver Huston, Professor in Mechanical Engineering, UVM; Dr. Tian Xia, Associate Professor in Electrical and Computer Engineering, UVM With the support of this CEACSE project, Drs. Wu, Liang, Yang, Dryver, and Dr. Xia submitted several research proposals collaboratively, and received one NSF grant (#1647175) "NSF US Ignite: Collaborative Research: Focus Area 1: Fiber Network for Mapping, Monitoring and Managing Underground Urban Infrastructure," UTC: \$299,884, UVM: \$298,525, 01/2017 - 12/2019. Also, during the process of implementing this project, one research lab, directed by Drs. Wu, Liang, and Li, has been set up at SimCenter.

Students Impacted	*Please list students including name, brief description of how they were impacted, what degree sought or when graduated, and any other relevant details.* The following students were involved in this project. With the support of this CEACSE project, most of them worked on this project with hourly pay. **Graduate students pursuing Ph.D degree in Computer Science:** Maxwell Omwenga, Mehran Ghafari. **Graduate students pursuing master degree in Computer Science:** Sharmila chackrawathy, Stuart Eudaly, Nada Alharbi, Maha Almaimani, Rabhu Bajracharya. **Undergraduate students pursuing bachelor degree in Computer Science**: Robert Slaughter, Dakila Ledesma, Christopher Davis, Alaykumar Patel, Suhail Arora, Austin Obyrne, Peter Zeglen, Derek Snyder, Morgan Sanborn, Izabella Arredondo. Nada (female) published one conference paper as the first author. Robert Slaughter, Dakila Ledesma, and Christopher Davis submitted one conference paper as co-authors.
Community and Broader Impacts	*Consider and discuss the technical and actual or potential societal impacts of your research project.* The broader impacts include educational experiences for graduate students and participating municipal utility officials in network-enabled sensing and urban infrastructure monitoring. The research conducted in this project was designed to determine methods of managing civil infrastructure in an urban setting, using network-enabled sensing and information processing techniques that are measurable, scalable and interoperable. Research results could enable cities to manage, maintain and grow their infrastructure in manners that improve service, sustainability and resilience, while reducing costs, energy consumption and wasted resources. Since many of the aging infrastructure lies in older cities, often subjected to economic distress and decay, this project has the potential to provide basic human needs and rights, and help to provide social justice through reliable low-cost provision of transportation, clean drinking water, functional storm and waste water sewers, heat, electricity and telecommunications. Additionally, there is significant potential for increased resilience and rapid effective management of recovery from disasters.
Work products reduced to practice; provide a bibliographical entry where appropriate	*Please include software, papers, presentations, posters, and creative works. Indicate Refereed Journal, Refereed Conference, Non-refereed Conference for each publication listed. For journal publications, indicate the impact factors where appropriate.* **Book chapter:** • Y. Liang, D. Wu, and et al., "Civil Infrastructure Serviceability Evaluation Based on Big Data," Guide to Big Data Applications, Springer, Editor: S. Srinivasan. Dec. 2016. **Journal papers:** • Y. Liang, D. Wu, and et al., "Big Data-enabled Multiscale Serviceability Analysis for Aging Bridges," Digital Communications and Networks, Elsevier, Volume 2, Issue 3, July 2016. • S. Guo, H. Zhang, P. Zhang, D. Wu, and D. Yuan, "Generalized 3-D Constellation Design for Spatial Modulation," IEEE Transactions on Communications, Vol. 65, No. 8, Aug. 2017. Journal impact factor: 4.058.

	Conference/workshop papers: • N. Alharbi, Y. Liang, and D. Wu, "A Data Preprocessing Technique for Gesture Recognition Based on Extended Kalman Filter," The BIGDATA4HEALTH Workshop, July 2017. • S. Guo, D. Wu, H. Zhang, and D. Yuan, "Queueing Network Model and Average Delay Analysis for Mobile Edge Computing," submitted, ICNC 2018, July 2017. • Y. Liang, D. Wu, R. Slaughter, C. Davis, D. Ledesma, and Z. Guo, "Virtual Tai-Chi System – A Big Data Enabled Modality for Rehabilitation," IEEE Big Data Conference, submitted, Aug. 2017. **Presentations:** • SimCenter Seminar: "Civil Infrastructure Serviceability Evaluation Based on Big Data," by Dr. Yu Liang, Jan. 20, 2017. • SimCenter Seminar: "Monitoring, Mapping and Modeling Underground Infrastructure for Smart Maintenance, Usage, and Sustainability," by Dr. Dalei Wu, Feb. 03, 2017. • UTC Research Dialogue: "Monitoring and Mapping Underground Infrastructure for Smart Maintenance and Usage," by Dr. Dalei Wu, April 12, 2017.
New inventions reduced to practice and when they will be formally disclosed;	*Please consider and include new software products that are subject to copyright but also methods and systems are potentially patentable. If you filed invention disclosures, patent or copyright applications during the period of performance, please indicate so here as well. If you wish to open source a software prototype data set, please state so; we will follow up with you with a disclosure process and guidance on how to proceed effectively for UTC and our research program, including required steps prior to doing so, and how properly to credit ownership to the UT system.* The teams plan to create a website to make collected data available to other researchers at minimal incremental costs.
Outreach & Collaboration	*Please list any visitors, workshops, or other collaborative events did you hold? Indicate the location (on campus, etc.).* • Dr. Dryver Huston visited the team two times on UTC campus. • The team participated the meetings with professors from UTC, University of Vermont, and technicians and officers from The Enterprise Center, Chattanooga Department of Transportation, Chattanooga Public Works, EPB, and Tennessee American Water. The Enterprise Center held the meetings in the Center building. • Four research proposals were submitted by collaborating with professors and researchers from University of Vermont, University of Cincinnati, University of Tennessee at Knoxville, Old Dominion University, Oak Ridge National Laboratory, and UTC Math Department.

EXTERNAL FUNDING

Proposal Submissions	*Please list all sponsored program proposals submitted during the reporting period related to this or previous CEACSE awards.* • NSF "US Ignite: Collaborative Research: Focus Area 1: Fiber Network for Mapping, Monitoring and Managing Underground Urban Infrastructure," $299,884, 01/2017 - 12/2019, PI: Dalei Wu, Co-PIs: Yu Liang, Li Yang. • NSF "Big DATA: IA: Collaborative Research: Critical Techniques for Data-driven Monitoring of Structural Health of Bridges in the United States," Program: Critical Techniques, Technologies and Methodologies for Advancing Foundations and Applications of Big Data Sciences and Engineering, submitted in 03/2017, $617,818, PI: Yu Liang, Co-PIs: Dalei Wu, Feng Bao, Cuilan Gao. • NIST, "Building Fire Resilient Communities with Emerging Computing Technologies," $1,508,098, submitted in 03/2017, PI: Li Yang, Co-PIs: Dalei Wu, Liang Yu. • The National Institute For Hometown Security, "Deployable Critical Infrastructure Data Viewer Incorporating Unmanned Systems Feeds," Program: National Infrastructure Protection Plan (NIPP) Security and Resilience Challenge, $315,864, submitted in 05/2017, PI: Li Yang, Co-PIs: Joseph Kizza, Dalei Wu.
Contracts / Awards Received	*List any awards or agreements received / executed related to this or previous CEACSE awards. Include sponsor name, sponsor program name (if applicable), project title, and award amount. If it is a non-funding agreement, identify by type (e.g., Data Use Agreement, Non Disclosure Agreement, Material Transfer Agreement, etc.).* • NSF (#1647175) "US Ignite: Collaborative Research: Focus Area 1: Fiber Network for Mapping, Monitoring and Managing Underground Urban Infrastructure," $299,884, 01/2017 - 12/2019, PI: Dalei Wu, Co-PIs: Yu Liang, Li Yang.
Sponsored Program Capacity Building Activities	*List all capacity-building activities in which you have engaged during the award period. Examples may include meeting with a sponsor program officer, attending an NSF/NIH/other sponsor regional workshop, participating in GWSW activities, attending on-campus workshops, etc.* • The participated in the Global City Team Challenge (GCTC) 2016 SuperCluster Kickoff, Washington DC, October 25-26, 2016, networking with other GCTC Action Cluster team leads. • Dr. Wu attended the IEEE INFOCOM, Atlanta, May 1-4 2017, meeting with NSF CNS program officers. • Dr. Wu participated in the Grant Writing Workshop cohort, 2017.

WHAT'S NEXT FOR THIS RESEARCH?

How will you follow up your CEACSE grant with work in the next 1,2, … 5 years?	The team will continue conduct in-depth study of the research topics identified in this CEACSE project. In the following year, we will focus on the development of novel machine learning algorithms and Bayesian networks for structural modeling and data analysis. Field experiment is under preparation by interacting with utility officials. In early next year, a demonstration of field testing will be carried out. The team will continue the collaborations that have been established through this CEACSE project to publish the generated research results, and submit external grant applications.
What other related research will you pursue (and with whom) in light of the support you've received from CEACSE?	Several smart city and public safety related projects including connected vehicles, railroad safety, fire fighting, and crime curbing, will be pursued by collaborating with UTC faculty and external researchers (Dr. Dryver Huston and Dr. Tian Xia from University of Vermont, Dr. Guirong Liu from University of Cincinnati, Dr. Zhongguo John Ma and Dr. Husheng Li from University of Tennessee at Knoxville, Dr. Yaohang Li from Old Dominion University, Mr. Richard Lusk from Oak Ridge National Laboratory, The Enterprise Center and other local organizations.)
Tell us anything else we should know about this work not described above.	
What barriers (if any) do you face to reach these next goals?	Funding is needed to support students working on the target research in the following years. The teaching load of the PI and Co-PIs is high, leaving insufficient time for conducting research and supervising students.

FINANCIAL ACCOUNTING

Financial Report:	**Total Award Amount:**	$95,610
	Cumulative Expenditures:	$84,580
	Remaining Award Amount:	$11,030

Please attach the following:

- *Final ledger report showing the final accounting for your award.*
- *Line item budget spreadsheet comparing your original, approved budget to how funds were actually expended.*
- *Updated budget narrative describing how funds were expended and how expense contributed to the achievement of project goals, objectives, and milestones.*

Supplemental Award Request	*Have you or do you anticipate applying for a supplemental award for any portion of the remaining balance? If so, please include the amount requested (or planned).*	$10,000

APPENDIX B

Awardee Project Reports

Extended from Previous Award periods into FY2017

THEC

Center for Excellence in Applied Computational Science & Engineering

CUMULATIVE FINAL REPORT

(Submit as a Microsoft Word document [not PDF] via e-mail to Tony-Skjellum@utc.edu with a copy to Joanne-Romagni@utc.edu)

PROJECT OVERVIEW

Lead PI	*List personnel as you would like for them to appear in a formal report – e.g., Dr. John Smith / John Smith, PhD, etc.* Dr. Joseph M. Kizza
Co-PI(s)	
Other Personnel	*Identify by type – senior personnel, technicians, graduate students, undergraduate students*
Project Title	Harnessing the power of Big Data in Arial Network Authentication and Medical Analysis and Predictions
Date Submitted	1/10/15
Award Start - End Date	6/30/17
Non-Technical Summary – 500 words or less	*Please provide a non-technical summary of your project that addresses the major objectives, accomplishments, and outcomes of your project. Discuss impacts of the project in terms of scholarly contributions to the field, scholarly outputs, student and community impacts, etc. Address how your project advanced or supported the mission of the SimCenter.* We now live in a world driven by digital data. To put this in perspective, all the digital data created, replicated, and consumed in a single year will about double every two years from now until 2020 based on a recent report of the digital universe [1]. Big data can generate significant financial value across sectors including healthcare, public administration, retail, manufacturing, etc. Advanced analytics has become a key basis of competition, underpinning new waves of productivity growth, innovation, and consumer surplus, which are essential to maintain advantages in the face of global competition. Analytics and data science are central to making "business, the global economy, and our society work better," according to Steve Mills, senior VP and group executive at IBM, and co-chair of the Big Data Commission. Data science and big data solutions are promising avenues of solving many of our society's challenges. Data scientists are hard at work developing new algorithms and protocols that will revolutionize the world as we know it today. One of the approaches of using big data to find new solutions to outstanding, sometimes unsolvable problems, is to revisit these old problems driven by big data concepts with new big data solution techniques. In this study, we will revisit two old problems and try to apply known big and

	streaming data solutions to them, and also try to develop new big data algorithms, where possible. The two case studies for this project are: airborne networks authentication using zero knowledge and medical analysis using boosted decision tree algorithms. These two cases are good candidates for big data solutions because their processes generate extensively huge amounts of high velocity and high volume, unstructured and sometimes, in the case of aerial networks, streaming data.
Project Web Page(s)	*Please provide the complete URL.* None

Please attach a Quad Chart using the following format as an example:
http://www.usamraa.army.mil/pages/baa_paa/fy06quaddirections_jsto_baa.pdf.

ACCOMPLISHMENTS & OUTCOMES

Project Overview

Provide a scientific / technical overview of your research project – hypothesis or scientific aims, methodologies and activities, outcomes, etc.

If the escalating rate of system attacks is any measure of system security, we are in for a an unprecedented period of system upheaval. Indeed a dangerous future for all of us who have come to depend of computing systems, big and small. We come to take, as normal, a situation where every the other day, there is a reported system hack and millions of users account, containing essential, if not vital personal information is hacked. All this mayhem is a result of our total dependence on an old outdated and antiquated authentication framework that depends on user passcode authentication. **Passcode-based authentication framework** is a security technique and process in which the users who attempt to log in to a server, a network, or some other secure system, is required to present a username and password pair as an authentication passcode. Upon receipt, the server compares the pair to its own stored username and password pair passcode. If there is a match, the server issues the user a security token, which the user presents to the service provider for authorization to gain the resources. The passcode-based framework, therefore, allows users to enter their passcode once in order to obtain a session token which allows them to fetch a specific resource(s) - without using their username and password again and again. Since there is storage of a user passcode(username and password) at the authenticating server, the passcode-based framework inherently has a vulnerability that makes all users potentially victims of hackers. That is the vulnerability that is ravaging our present day system and causing the endemic hacking that does not have an end in sight. Unless and until we plug this vulnerability, no system will ever be safe.

The scientific and technical overview of this project is that the current **passcode-based framework** inherently has a vulnerability that makes all users potentially victims of to hackers. That this is the vulnerability that is ravaging our present day system and causing the endemic hacking that does not have an end in sight. Unless and until we plug this vulnerability, no system will ever be safe. **There must be a better and scalable framework.**

The goal of this study is to develop a **passcode-free framework**, that does not depend a user provided passcode and, consequently to server-based storage of the pair. If and once there is no storage of user provided anything, hackers will never break into systems and get away with valuable loot.

Exchange of information and data between two or more communicating entities depends a great deal on trust between the communicating entities. For fruitful communication, each side in the exchange must be able to trust the other and the data being exchanged. The challenge always is how to build the trust to a threshold required for the authentication and authorization of the entity without any exchange of authenticating passcodes.

List of Objectives / Aims / Major Milestones Proposed	Cumulative Outcomes / Accomplishments
To develop a passcode-free framework, that does not depend a user provided passcode and, consequently to server-based storage of the pair	
• **Study and develop Zero Knowledge Proofs(ZKP)**	Developed a new ZKP - Feige-Fiat-Shamir ZKP Scheme Revisited (Joseph M. Kizza)
• **Develop a Simulation** ○ **Distrust/Second-hand verification with one path to the Prover** ○ **Distrust/Second-hand verification with multiple paths to the Prover** ○ **Distrust/Second-hand verification by two adjacent asynchronous first-hand Verifiers**	done
• **The Trust Propagation Algorithm**	**In progress** - In standard Zero-Knowledge proofs, the trust of a new flying entity (Prover) seeking authentication to use the airborne network's services is computed by the network Verifier (first contact network node(s)). Traditional Zero-Knowledge Proofs require that Prover trust by the Verifier starts with an apriori trust of 0.5. This then grows with every correct response by the Prover to the Verifier's challenges. The Prover is given access to network services when the calculated apriori trust exceeds a threshold value λ. In the proposed algorithm, it is required that beside the one Verifier, there may be one or more additional first layer contact verifiers (inside network nodes). Also required is that every inside verifier within the network must contribute in the overall trust computation of the outside entity seeking network services. Each verifier starts its computation with an apriori trust of 0.5 of the immediate neighbor verifier. This is the first hand trust probably arrived at through direct observation. In addition to the apriori trust, each verifier in the network calculates entity trust based on second hand information it gets from its nearest neighbor if it is an internal verifier, or the information it gets from the Prover(entity) if it is a front line Verifier

Add rows as needed.

Challenges & Strategies Used to Address / Overcome:

Discuss any challenges or barriers that you encountered, particularly if you were impeded from achieving the objectives and milestones approved in your proposal.

The most difficult problems we are encountering are:

(1) to be able to build a network mess that will respond to the nearest neighbor response algorithms in a timed manner.

(2) To find a way to design an entity (i.e. device) request **authentication scheme – based on a request-response, trust-propagation, nearest neighbor and majority vote algorithms** and send back an authorization to an entity seeking authentication and authorization in a given ***time window***. Perhaps this is still the biggest challenge we have to overcome.

What didn't work? What did you disprove or learn from the parts that didn't meet your initial concept at the proposal?

Describe any areas where you did not meet goals; negative results are important too and should be explained and documented. Mostly, what did you learn besides what you achieved whether it met your expectations at the outset of this effort?

We tried to do an airborne entity authentication based on a cluster of servers and this did not come out right. WE were unable to move the entity fast enough.

IMPACT & OUTCOMES

Impact on the career(s) of the PI, the co-PIs, and key collaborators	The impact of this project has been really great. I was able to meet with and work with scientists the US Air Force research Lab in Rome New York. Over the last couple of years, I have met with and collaborated with several other scholars. The experience has been rewarding.
Students Impacted	*Please list students including name, brief description of how they were impacted, what degree sought or when graduated, and any other relevant details.* Starting with fall 2015 through fall 2016, I hired Mr. Jenner Dai, then an MS student to work on this project with me. Now Mr. Dai is a PhD student and still working under me for his PhD thesis research based on this work.
Community and Broader Impacts	*Consider and discuss the technical and actual or potential societal impacts of your research project.* If this were to work, and I am sure it will, its impact will be phenomenal as it will make hacking, as we know it today, something of the past.
Work products reduced to practice; provide a bibliographical entry where appropriate	*Please include software, papers, presentations, posters, and creative works. Indicate Refereed Journal, Refereed Conference, Non-refereed Conference for each publication listed. For journal publications, indicate the impact factors where appropriate.* 1. Kizza, Joseph. M. Fiege-Fiat-Shamir Revisited. Journal of Computing and ICT Research, Vol. 4, No. 1, pp. 9-19. http://www.ijcir.org/volume4-number1/article2.pdf. 2. Kizza, Joseph M. Data Transfer Speed up in the Revised Feige-Fiat-Shamir ZKP Protocol, Technical Report – TR-09-2, USAF Research Laboratory, Rome, NY.
New inventions reduced to practice and when they will be formally disclosed;	*Please consider and include new software products that are subject to copyright but also methods and systems are potentially patentable. If you filed invention disclosures, patent or copyright applications during the period of performance, please indicate so here as well. If you wish to open source a software prototype data set, please state so; we will follow up with you with a disclosure process and guidance on how to proceed effectively for UTC and our research program, including required steps prior to doing so, and how properly to credit ownership to the UT system.* None

Outreach & Collaboration	*Please list any visitors, workshops, or other collaborative events did you hold? Indicate the location (on campus, etc.).* None

EXTERNAL FUNDING

Proposal Submissions	*Please list all sponsored program proposals submitted during the reporting period related to this or previous CEACSE awards.* Based on this research work, I have submitted several funding proposals including: • Title of Project: IUSE/PFE:RED: Institutional Transformation of the Computer Science Education System for the 21st Student; Source of Support: IUSE/PFE:RED; Total Award Amount: $1,387,626 (PI: Kizza) • Title of Project: Strengthening the National Cyber Security Workforce: SFS program at University of Tennessee at Chattanooga; Source of Support: NSF CyberCorps; Total Award Amount: $1,897,076 (Co-PI; PI: Li Yang). • EAGER: Curbing Crimes in Urban Areas Using Emerging Computing Technologies $280,832 (Co-PI) (PI: Dr. Li Yang). • US Ignite: Focus Area 1: Improving Safety in Urban Neighborhoods using Cyber Physical Systems - $596,551 (Co-PI) (PI Dr. Farah Kandah). • NRT-DESE: Data in the GigCity: A Unified and Comprehensive Platform for Education and Research on Data Science and Engineering to Push Revolutionary Urbanization - • $2,770,752 (Co-PI), (PI: Dr. Mina Sartipi). I am planning to write more proposals from this work. In fact, according to Researchgate, my publication "Feige-Fiat-Shamir ZKP Scheme Revisited", based on this work has been cited three times in the last year alone.

Contracts / Awards Received	*List any awards or agreements received / executed related to this or previous CEACSE awards. Include sponsor name, sponsor program name (if applicable), project title, and award amount. If it is a non-funding agreement, identify by type (e.g., Data Use Agreement, Non Disclosure Agreement, Material Transfer Agreement, etc.).* None
Sponsored Program Capacity Building Activities	*List all capacity-building activities in which you have engaged during the award period. Examples may include meeting with a sponsor program officer, attending an NSF/NIH/other sponsor regional workshop, participating in GWSW activities, attending on-campus workshops, etc.* During the two years of the award, I have attended several capacity building activities including: • NSF Merit Review surveys • NSF Review Panel - S&CC: Smart & Connected Community • Attended several on-campus workshops including those in CECS.

WHAT'S NEXT FOR THIS RESEARCH?

How will you follow up your CEACSE grant with work in the next 1,2, … 5 years?	• continuing my research work with supervision of Mr. Dai – PhD research and dissertation in the research area. • Continue to write research grants • Continue to publish.
What other related research will you pursue (and with whom) in light of the support you've received from CEACSE?	• This work is becoming more applicable in the developing Internet of Things (IoT) authentication. • We are continuing our work (which started at the US Air Force Research Lab) on Authentication in Airborne Networks.

Tell us anything else we should know about this work not described above.	The possibilities and potential of this work, if it is successful, are overwhelming.
What barriers (if any) do you face to reach these next goals?	Funding. If I were to get funds to hire a post-doc who will work along with a few undergraduate and graduate students, this work would move faster.

FINANCIAL ACCOUNTING

Financial Report:	**Total Award Amount:**	$50,000
	Cumulative Expenditures:	$
	Remaining Award Amount:	$

Please attach the following:

- *Final ledger report showing the final accounting for your award.*
- *Line item budget spreadsheet comparing your original, approved budget to how funds were actually expended.*
- *Updated budget narrative describing how funds were expended and how expense contributed to the achievement of project goals, objectives, and milestones.*

Original Budget

Category	**Year 1**	**Total**
A. Personnel		
1. Graduate Students (2 students supported for a year - $20,762 for one student where $8,762 is in state tuition waiver and 12,000 is stipend in AY)	$41,524	$41,524
2. Faculty (1.5 month summer support)	$15,900	$15,900
B. Equipment. 10 Raspberry Pi B+ (B Plus) Complete Starter Kit -- Includes Quick Start Guide - @ at $59.99 + tax	$653.89	$653.89
C. Benefits (rate is 20%)	$3,180	$8,829
D. Total Direct Costs	$61,257.89	$66,906.89

Extension Budget:

Category	**Year 1**	**Total**
A. Faculty. summer pay	$6000	$6000
B. Ungraduated Students). 2 graduate students @$12/hr for 15/wk for 9m	$3240	$3240
C. Benefits (rate is 20%)	$848	$848
D. Travel	$1,425.52	$1,425.52

E. Total Direct Costs	$13,713.52	$13,713.52

How Budget was used:
(see attached file).
The funded granted to me, including an extension, were very useful to me and helped me to expand my research work. With more funding, mostly sought externally, I hope you achieve my set goals.

Thank you for funding me for the last two years.
Joseph M. Kizza

Supplemental Award Request	*Have you or do you anticipate applying for a supplemental award for any portion of the remaining balance? If so, please include the amount requested (or planned).* No	$

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CUMULATIVE FINAL REPORT

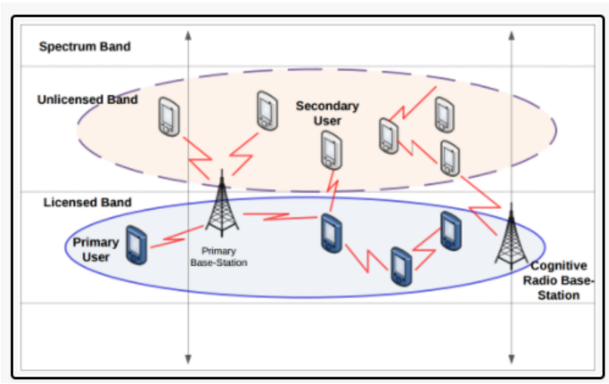
(Submit as a Microsoft Word document [not PDF] via e-mail to Tony-Skjellum@utc.edu with a copy to Joanne-Romagni@utc.edu)

PROJECT OVERVIEW

Lead PI	*List personnel as you would like for them to appear in a formal report – e.g., Dr. John Smith / John Smith, PhD, etc.* Farah Kandah, PhD
Co-PI(s)	None
Other Personnel	*Identify by type – senior personnel, technicians, graduate students, undergraduate students* None
Project Title	A Robust Network Design in Cognitive Radio Networks
Date Submitted	May 30, 2014
Award Start - End Date	July 1, 2014 – June 30, 2017
Non-Technical Summary – 500 words or less	*Please provide a non-technical summary of your project that addresses the major objectives, accomplishments, and outcomes of your project. Discuss impacts of the project in terms of scholarly contributions to the field, scholarly outputs, student and community impacts, etc. Address how your project advanced or supported the mission of the SimCenter.* This project's aim was to improve the communications and the connectivity in wireless networks. In supporting the SimCenter mission, our team worked in the area of urban systems and public safety with an aim of maintaining an effective emergency communications and connectivity among different levels of users to support the network in handling different types of traffic. For instance, in an emergency situation, communications among first responders in the scene and communications between field personnel and control centers must be handled smartly and efficiently to avoid any delay or interruption that might result in delaying the response or containing the situation.
Project Web Page(s)	*Please provide the complete URL.*

Please attach a Quad Chart using the following format as an example:
http://www.usamraa.army.mil/pages/baa_paa/fy06quaddirections_jsto_baa.pdf.

THEC Center for Excellence in Applied Computational Science & Engineering
Technology Area of Interest: Wireless Networks
Proposal Title: A Robust Network Design in Cognitive Radio Networks



Operational Capability to be provided:

Our overall goal is to address the challenges in wireless network that would degrade the communication performance and develop a new practical and theoretical approach for routing and communication robustness in CRNs.

Proposal Technical Approach:

- Evaluate the behavior of CRNs under high traffic demand.
- Combining the full spectrum knowledge and the local spectrum knowledge to create an adaptable connectivity in the network that will lead to high satisfied ratio among the network users.
- Evaluate the proposed scheme to show the network enhancements.

Equipment to be used:

- All the experiments will be simulated and run on the lab computers.
- An upgrade to the lab computers is required to speed up the run of the simulation.
- A set of Raspberry Pi models will be purchased to be used to configure a testbed to be used to run our experiments.

Deliverables:

- Quarterly reports describing the status of the project.
- The Code and the manual will be posted on GitHub and will be provided upon request.

ACCOMPLISHMENTS & OUTCOMES

Project Overview

Provide a scientific / technical overview of your research project – hypothesis or scientific aims, methodologies and activities, outcomes, etc.

In this project we investigated the cognitive radio technology and its ability in supporting the network in emergency and critical situations.
We focused on successful transmission taking into consideration routing, interference, energy consumption, and packets drop rate.
As an outcome of this project, we were able to provide an enhancement in the network by creating a dynamic shared environment between the primary and the secondary users that led to handling the network traffic and satisfying different users' requests more efficiently.

List of Objectives / Aims / Major Milestones Proposed	Cumulative Outcomes / Accomplishments
Evaluating the behavior of CRN	This part of the project led us to understand how the CRN performs under different types of traffic and how the primary users and the secondary users perform in these situations.
Provide a wide understanding of the spectrum to different users in the network	With this, we were able to manage the network more efficiently and eventually avoiding interruptions in the secondary users' transmissions due to the return of the primary users.
Evaluating the proposed scheme to show the enhancement provided to the network	We simulated the topology and the cognitive radios and were able to run different experiments and use cases that proved that the proposed scheme was able to enhance the way in which the network can handle traffic and create a fair-share environment between the primary and the secondary users.

Add rows as needed.

Challenges & Strategies Used to Address / Overcome:

Discuss any challenges or barriers that you encountered, particularly if you were impeded from achieving the objectives and milestones approved in your proposal.

Some challenges that we encounter was through running the simulation. We were trying to cover a number of cases to test the network performance under different densities which end up requiring us to seek high computing powers. With the help of the SimCenter supercomputers, we were able to run our simulation and get the results.

What didn’t work? What did you disprove or learn from the parts that didn’t meet your initial concept at the proposal?
Describe any areas where you did not meet goals; negative results are important too and should be explained and documented. Mostly, what did you learn besides what you achieved whether it met your expectations at the outset of this effort? We were planning to build an actual testbed that can be used to run actual experiment to support our simulations. We started our research in this area but it required a lot of time to learn about the equipment and the software to be used. We currently continuing our investigation in this area and intend to build this testbed in the near future.

IMPACT & OUTCOMES

Impact on the career(s) of the PI, the co-PIs, and key collaborators	This research helped the PI to understand how CRN works and how to manage traffic between primary and secondary users. This research will be used to introduce students to this technology in the computer networking courses that the PI is teaching in the coming semesters.
Students Impacted	*Please list students including name, brief description of how they were impacted, what degree sought or when graduated, and any other relevant details.* Two students worked on this project: - Jesse Whitehead was the first student to work on this project. During his research he learned a lot about wireless networks and using the simulation. Currently he is working at BlueCross BlueShield as he graduated in 2016 with a Master degree in Computer Science. - Steven Schmitt continued the work on this project. He finished his undergraduate degree in 2016 and he is currently enrolled in the Master program at UTC. Mr. Schmitt focused his research on Software Defined Network and he is currently working on building an SDN testbed to be used as a platform to test our future research in this field.
Community and Broader Impacts	*Consider and discuss the technical and actual or potential societal impacts of your research project.* The high mobile and wireless demand among network users and the ability to dynamically handling networking traffic efficiently and smartly utilizing the spectrum will support future network communication in different fields and will have a wide broader impact on many generations to come.

Work products reduced to practice; provide a bibliographical entry where appropriate	*Please include software, papers, presentations, posters, and creative works. Indicate Refereed Journal, Refereed Conference, Non-refereed Conference for each publication listed. For journal publications, indicate the impact factors where appropriate.* - F. Kandah and J. Whitehead, "*Cluster-Based Dynamic Backup in Cognitive Radio Networks*," *2017 International Conference on Computing, Networking and Communications (ICNC)*, Santa Clara, CA, 2017, pp. 740-744. - - Farah Kandah, Steven Schmitt, and Jesse Whitehead, "*Using Hybrid Spectrum Handoff Towards Fairness Usage in Cognitive Radio Networks*", **IJIPM: International Journal of Information Processing and Management**, Accepted 2017.
New inventions reduced to practice and when they will be formally disclosed;	*Please consider and include new software products that are subject to copyright but also methods and systems are potentially patentable. If you filed invention disclosures, patent or copyright applications during the period of performance, please indicate so here as well. If you wish to open source a software prototype data set, please state so; we will follow up with you with a disclosure process and guidance on how to proceed effectively for UTC and our research program, including required steps prior to doing so, and how properly to credit ownership to the UT system.*
Outreach & Collaboration	*Please list any visitors, workshops, or other collaborative events did you hold? Indicate the location (on campus, etc.).* We will be seeking new collaboration with the police department and the City of Chattanooga.

EXTERNAL FUNDING

Proposal Submissions	*Please list all sponsored program proposals submitted during the reporting period related to this or previous CEACSE awards.* • NSF CAREER: Adopted Networking Design to Improve the Network Performance in Crowded and Critical Situations. • NSF US Ignite: WECAAN - Wide Emergency Crowdsourced Automated Adaptive Networking System.

Contracts / Awards Received	*List any awards or agreements received / executed related to this or previous CEACSE awards. Include sponsor name, sponsor program name (if applicable), project title, and award amount. If it is a non-funding agreement, identify by type (e.g., Data Use Agreement, Non Disclosure Agreement, Material Transfer Agreement, etc.).* • NSF CyberCorps: Collaborative Research: Building Security Education Capacity through POGIL.
Sponsored Program Capacity Building Activities	*List all capacity-building activities in which you have engaged during the award period. Examples may include meeting with a sponsor program officer, attending an NSF/NIH/other sponsor regional workshop, participating in GWSW activities, attending on-campus workshops, etc.* The PI participated in the Grant Writing Workshop held at the College of Engineering and Computer Science.

WHAT’S NEXT FOR THIS RESEARCH?

How will you follow up your CEACSE grant with work in the next 1,2, … 5 years?	Our next step in this research is to investigate different techniques in how to improve the network performance in Cognitive Radio as well as defending against threats targeting the network.
What other related research will you pursue (and with whom) in light of the support you’ve received from CEACSE?	We will focus our future research to create robust automobile and aerial vehicle networks through the development of cybersecurity layers that can advance the next generation cyber-workforce in standing against threats that target the safety of human lives.
Tell us anything else we should know about this work not described above.	

What barriers (if any) do you face to reach these next goals?	Seeking more funds to support our future research and train new students to conduct research and use our developed systems.

FINANCIAL ACCOUNTING

Financial Report:	**Total Award Amount:**	$45,000
	Cumulative Expenditures:	$44,034.54
	Remaining Award Amount:	$965.46

Please attach the following:

- *Final ledger report showing the final accounting for your award.*
- *Line item budget spreadsheet comparing your original, approved budget to how funds were actually expended.*
- *Updated budget narrative describing how funds were expended and how expense contributed to the achievement of project goals, objectives, and milestones.*

Supplemental Award Request	*Have you or do you anticipate applying for a supplemental award for any portion of the remaining balance? If so, please include the amount requested (or planned).*	$

Final Ledger report:

U046413030 Computer science
R041302182 CEACSE 15 Kandah Cognitive Radio N

The University of Tennessee
LEDGER

Reporting Period: Close of FY 2017
Reporting Status: Final

Project Status:	Open	Endowment:	
Begin Date:	07-01-2014 End Date: 06-30-2017	Book Value:	Last Qtrly Distrb.
Principal Investigator:	Kandah, Farah	Market Value:	On
Functional Area:	Research		
Project Type:	22 Center of Excellence		

S O U R C E S & U S E S O F F U N D S

S O U R C E S O F F U N D S	Current Month	Budget	Cumlatv Actuals	Remaining
Gifts, Grants & Bequests-Receipts	5,573.28		44,034.54	44,034.54-
Sponsored Projects Billings		45,000		45,000.00
TOTAL SOURCES OF FUNDING	5,573.28	45,000	44,034.54	965.46

U S E S O F F U N D S	Current Month	Budget	Commitments	Cumlatv Actuals	Remaining
TOTAL COSTS		45,000		44,034.54	965.46

BALANCE

In accordance with university policy, I have reviewed the charges shown on this ledger and either verified their accuracy and appropriateness to this fund or identified and reported discrepancies for correction through proper channels.

Responsible Person

Date: ____________

Line Item Budget:

R041302182

THEC CEACSE 15 Kandah Cognitive Radio Networks	**Original Budget**	**Fianl Budget**
Category	**Amount Requested**	
A. Senior Personnel - *List each individual separately. Include details on how the budgeted amount was calculated. Specify Summer Pay or Release Time and the percent of effort budgeted.*		
1. PI	$11,748	$11,748.00
EXAMPLE: Dr. X will work 1 summer month on this project. 9-month salary is $90,000 for 9 months x 1 summer month = $10,000		
B. Other Personnel		
1. Graduate Students	$12,087.49	$11,688.00
2. Undergraduate students	$1,912.51	$1,500.00
C. Fringe Benefits		
actual rate (full time faculty)	$3,041	$2,284.00
9% of salary (part time staff & students)		$183.00
D. Equipment		
**only items over $5000 are considered equipment*		
E. Travel		
a. Domestic (conferences, etc.)	$1,861	$1,220.00
b. Foreign		
F. Other Direct Costs		
1. Materials and Supplies	$3,100	$5,127.00
(Note: items under $5000, such as computers, and other materials related to the activities of the project go here)		
2. Publication Costs / Documentation/Dissemination		
3. Consultant Services		
Note: if you include an external project evaluator, other individuals outside of the UT system, etc., you include them here		
4. Tuition	$10,080	$10,080.00
5. Subawards		
6. Other (Contractual & Special Services)	$1,170	$1,170.00
G. Total Direct Costs		$45,000.00
TOTAL FUNDS REQUESTED	$45,000	$45,000.00

THEC
Center for Excellence in Applied Computational Science & Engineering

CUMULATIVE FINAL REPORT
(Submit as a Microsoft Word document [not PDF] via e-mail to Tony-Skjellum@utc.edu with a copy to Joanne-Romagni@utc.edu)

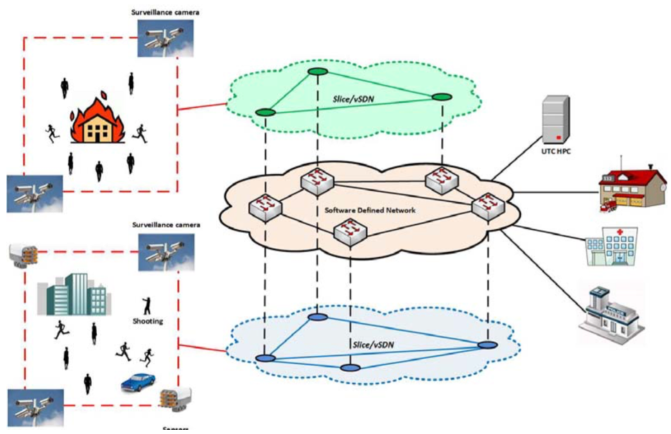
PROJECT OVERVIEW

Lead PI	*List personnel as you would like for them to appear in a formal report – e.g., Dr. John Smith / John Smith, PhD, etc.* Farah Kandah, Phd
Co-PI(s)	--------
Other Personnel	*Identify by type – senior personnel, technicians, graduate students, undergraduate students* --------
Project Title	Quality of Service Assurance using GENI
Date Submitted	May 1, 2013
Award Start - End Date	July 1, 2013 – June 30, 2017
Non-Technical Summary – 500 words or less	*Please provide a non-technical summary of your project that addresses the major objectives, accomplishments, and outcomes of your project. Discuss impacts of the project in terms of scholarly contributions to the field, scholarly outputs, student and community impacts, etc. Address how your project advanced or supported the mission of the SimCenter.* This project started with a focus on supporting real-time applications using the Global Environment and Networking Innovation to improve the quality of service over networks. To support the SimCenter efforts in the field of Urban System, our team worked on developing a collaborative emergency system with the ability to provide real-time reports with ample information to emergency responders to make accurate decisions about the incidents. The broader impact of this project is its ability to provide a panoramic view of the incident to give the responders ample information leading to better decision making regarding the resources needed to control the incident before heading to the scene. Moreover, with high mobile penetration around the country and successfully using it with mobile carriers to be provided free as an emergency app on their platforms, will give a national wide boarder impact for generation to come.

Project Web Page(s)	*Please provide the complete URL.* https://fkandah.github.io/VideoGENI-Application/

Please attach a Quad Chart using the following format as an example:
http://www.usamraa.army.mil/pages/baa_paa/fy06quaddirections_jsto_baa.pdf.

THEC Center for Excellence in Applied Computational Science & Engineering
Technology Area of Interest: Computer Networks
Proposal Title: Quality of Service Assurance using GENI



Operational Capability to be provided:

Our overall goal is to enhance the currently adopted emergency reporting system, by capturing audio, video and text messaging data, quickly analyzing it and reporting it with adequate and precise amount of information about the incident with enough lead time to enable the dispatcher and the response team to make accurate decisions leading to the shortest elapsed time delay to efficiently contains the situation.

Proposal Technical Approach:

- Data gathering entity: this entity consists of a set of fixed cameras for audio/video data gathering, and users' smart devices for crowdsourced (audio/video/text) data gathering. The focus here is to carry the task of monitoring the area of interest and feed the gathered data to the system.
- Networking/Communication entity: this entity focusses on data transmission and communication to facilitate data and information transmission in real-time while avoiding any delays that might occur due to bandwidth limitations or traffic congestion.
- Reporting/Notifying entity: this entity will focus on reporting the incident to the dispatcher based on the collected data.

Equipment to be used:
Task 1: IP cameras and Smart Phone devices will be used to provide the data to the system.
Task 2: GENI and SDN Openflow framework will be used to facilitate the communication and traffic monitoring.
Task 3: GENI will be used to develop a cloud based dashboard.

Deliverables:

- Quarterly reports describing the status of the project.
- The Code and the manual will be posted on GitHub and will be provided upon request.

ACCOMPLISHMENTS & OUTCOMES

Project Overview

Provide a scientific / technical overview of your research project – hypothesis or scientific aims, methodologies and activities, outcomes, etc.

Our goal started with developing a multi-path routing scheme to enhance the network performance, thus ensuring a better quality of service taking into consideration the network delay and the throughput optimization to assure a near real-time data transmission.

We studied ways of improving the ability of the network in supporting real-time transmissions through avoiding transmission delays as well as optimizing the throughput usage to achieve the desired performance. Dynamic disjoint multipath scheme was designed to support the reliability and the survivability of the network.

List of Objectives / Aims / Major Milestones Proposed	Cumulative Outcomes / Accomplishments
- Improve the network performance in handling the traffic more efficiently and support the network survivability. - Improve data and information transmission and delivery to overcome data overloads due to huge amount of data transmission in near-real time between different entities in the reporting system.	- This objective was achieved by developing a multi-path routing scheme that smartly distribute the network traffic to utilize the resources more efficiently. - To automate the network utilization process, we developed a dynamic and adaptable network design over software-defined network that allow the network to dynamically handling the traffic and balance the load in the network.
- Improve data capture at the incident scene to address the challenges and possibilities of error and misunderstanding common in verbal description of the incidents. - Improve and speed up the reporting of analyzed information to the dispatcher. This will address the challenges of reducing the delays that might occur between the time of reporting and describing the incident to the time of making	- A cloud based application was developed over GENI that allow users to video stream the incident to a dashboard that allows the dispatcher to view concurrent streams about the incidents and be able to allocate first responders to be sent to the scene. - A mobile app was also developed to allow users to capture and video stream the incidents in real-time to the dispatcher dashboard.

decisions.	

Challenges & Strategies Used to Address / Overcome:

Discuss any challenges or barriers that you encountered, particularly if you were impeded from achieving the objectives and milestones approved in your proposal.

To address the challenges in dynamically handling the network traffic, we consider traffic engineering and traffic pattern recognition through monitoring the network statistics in real-time, such as drop rate, throughput requirement, and network capacity. With this we were able to automate the process of smartly routing the network traffic to utilize the network more efficiently and eventually allow the network to handle more traffic.

What didn't work? What did you disprove or learn from the parts that didn't meet your initial concept at the proposal?

Describe any areas where you did not meet goals; negative results are important too and should be explained and documented. Mostly, what did you learn besides what you achieved whether it met your expectations at the outset of this effort?

Maintaining the reporting and managing traffic in real-time or close to real-time was a challenge and we are still looking in enhancing our developed schemes to allow the network to adopt to the traffic demand and support the network survivability in case of an attack. As we maintained a single controller to control the network and update the flow in the network switches, we are still investigating different techniques that allow us to virtualize the controller in the network to avoid a single point of failure to allow the network to handle any failure issues due to a hardware/software failure or a network attack.

IMPACT & OUTCOMES

Impact on the career(s) of the PI, the co-PIs, and key collaborators	This project was a great help for the PI in learning different techniques in traffic engineering and how software can be used to manage the traffic in the network more efficiently. The PI will continue his work in this field and investigate new techniques to help advancing his research capacity and apply the concept to different fields in computer networks.

Students Impacted	*Please list students including name, brief description of how they were impacted, what degree sought or when graduated, and any other relevant details.* Three students worked on this project: - Dustin Howerton peruse his undergraduate degree in Computer Science. Mr. Howerton graduated in 2016. Working on this project, Mr. Dustin learned a great amount of programming languages that served him well in finding a job after his graduation. - Steven Schmitt worked on this project and he finished his undergraduate degree in 2016 and he is currently enrolled in the Master program at UTC. Mr. Schmitt focused his research on Software Defined Network and he is currently working on building an SDN testbed to be used as a platform to test our future research in this field. - Jesse Whitehead graduated in 2016 with a Master degree in Computer Science. During his degree he worked on developing the multi-path scheme used in this project. He is currently working at Blue Cross Blue Shield of Chattanooga.
Community and Broader Impacts	*Consider and discuss the technical and actual or potential societal impacts of your research project.* The high mobile penetration around the country and successfully using our app with mobile carriers to be provided free as an emergency app on their platforms, will give a national wide boarder impact for generation to come.
Work products reduced to practice; provide a bibliographical entry where appropriate	*Please include software, papers, presentations, posters, and creative works. Indicate Refereed Journal, Refereed Conference, Non-refereed Conference for each publication listed. For journal publications, indicate the impact factors where appropriate.* - Dustin Howerton, "*Video Streaming over GENI*" **ACM Southeast Conference 2015** – Poster - Farah Kandah, and Jesse Whitehead, "Energy-aware Multipath Provisioning in Wireless Mesh Networks", ***2015 12th Annual IEEE Consumer Communications and Networking Conference (CCNC)***, Las Vegas, NV, 2015, pp. 473-478. - Farah Kandah and Jesse Whitehead, *"Trust-based Survivability Provisioning in Wireless Mesh Networks"*, ***IJIPM: International Journal of Information Processing and Management****, Vol. 7, No. 2, pp. 36 ~ 47, 2016* - Farah Kandah and Steven Schmitt, "Towards a Smart, Dynamic, and Adaptable Network Design Using Virtual Slicing over Software-Defined Network", **IEEE Consumer Communications and Networking Conference (CCNC)** (Under review) - Steven Schmitt and Farah Kandah, "Mitigating Denial of Service Attacks using Traffic Pattern Recognition over Software-Defined Network", **IEEE Consumer Communications and Networking Conference (CCNC)** (Under review)

New inventions reduced to practice and when they will be formally disclosed;	*Please consider and include new software products that are subject to copyright but also methods and systems are potentially patentable. If you filed invention disclosures, patent or copyright applications during the period of performance, please indicate so here as well. If you wish to open source a software prototype data set, please state so; we will follow up with you with a disclosure process and guidance on how to proceed effectively for UTC and our research program, including required steps prior to doing so, and how properly to credit ownership to the UT system.*
Outreach & Collaboration	*Please list any visitors, workshops, or other collaborative events did you hold? Indicate the location (on campus, etc.).* We are in the process of seeking collaborations with Clemson University and the Department of Transportation at Chattanooga.

EXTERNAL FUNDING

Proposal Submissions	*Please list all sponsored program proposals submitted during the reporting period related to this or previous CEACSE awards.* • NSF US Ignite: Focus Area 1: Improving Safety in Urban Neighborhoods using Cyber Physical Systems. • DOD Early Career program: Software Defined Network Utilization to Improve the Network Performance in Collaborative Virtual Labs. • NSF CAREER: Adopted Networking Design to Improve the Network Performance in Crowded and Critical Situations. • CRISP: Using Internet Technology to Connect Captive Chimpanzees. • Cyber Research Institute (CRI), Simulation of Trust and Distrust Propagation in Airborne Networks Authentication. • NSF US Ignite: WECAAN - Wide Emergency Crowdsourced Automated Adaptive Networking System.
Contracts / Awards Received	*List any awards or agreements received / executed related to this or previous CEACSE awards. Include sponsor name, sponsor program name (if applicable), project title, and award amount. If it is a non-funding agreement, identify by type (e.g., Data Use Agreement, Non Disclosure Agreement, Material Transfer Agreement, etc.).* • NSF CyberCorps: Collaborative Research: Building Security Education Capacity through POGIL.

Sponsored Program Capacity Building Activities	*List all capacity-building activities in which you have engaged during the award period. Examples may include meeting with a sponsor program officer, attending an NSF/NIH/other sponsor regional workshop, participating in GWSW activities, attending on-campus workshops, etc.* The PI participated in the Grant Writing Workshop held at the College of Engineering and Computer Science.

WHAT'S NEXT FOR THIS RESEARCH?

How will you follow up your CEACSE grant with work in the next 1,2, … 5 years?	Our next step in this research is to investigate different techniques in Software-defined networking field that allow us to enhance the network performance in handling traffic smartly as well as investigating different ways in supporting the network survivability against single point of failure due to software/hardware failures or network attacks.
What other related research will you pursue (and with whom) in light of the support you've received from CEACSE?	We will focus our future research to create robust automobile and aerial vehicle networks through the development of cybersecurity layers that can advance the next generation cyber-workforce in standing against threats that target the safety of human lives.
Tell us anything else we should know about this work not described above.	
What barriers (if any) do you face to reach these next goals?	Seeking more funds to support our future research and train new students to conduct research and use our developed systems.

FINANCIAL ACCOUNTING

Financial Report:	**Total Award Amount:**	$65,000
	Cumulative Expenditures:	$64,953.40
	Remaining Award Amount:	$46.60

Please attach the following:

- *Final ledger report showing the final accounting for your award.*
- *Line item budget spreadsheet comparing your original, approved budget to how funds were actually expended.*
- *Updated budget narrative describing how funds were expended and how expense contributed to the achievement of project goals, objectives, and milestones.*

Supplemental Award Request	*Have you or do you anticipate applying for a supplemental award for any portion of the remaining balance? If so, please include the amount requested (or planned).* No	$

Final Ledger:

U046413030 Computer science
R041302151 CEACSE 14 Kandah GENI

The University of Tennessee
LEDGER

Reporting Period: Close of FY 2017
Reporting Status: Final

Project Status:	Open	Endowment:	
Begin Date:	07-01-2013 End Date: 06-30-2017	Book Value:	Last Qtrly Distrb.
Principal Investigator:	Kandah, Farah	Market Value:	On
Functional Area:	Research		
Project Type:	22 Center of Excellence		

S O U R C E S & U S E S O F F U N D S

S O U R C E S O F F U N D S	Current Month	Budget	Cumlatv Actuals	Remaining
Gifts, Grants & Bequests-Receipts	1,899.11	45,000	64,953.40	19,953.40-
Sponsored Projects Billings		20,000		20,000.00
TOTAL SOURCES OF FUNDING	1,899.11	65,000	64,953.40	46.60

U S E S O F F U N D S	Current Month	Budget	Commitments	Cumlatv Actuals	Remaining
TOTAL COSTS		65,000		64,953.40	46.60

BALANCE

In accordance with university policy, I have reviewed the charges shown on this ledger and either verified their accuracy and appropriateness to this fund or identified and reported discrepancies for correction through proper channels.

Responsible Person

Date: ____________

Line Item Budget:

R041302182 THEC CEACSE 14 Kandah GENI	Original Budget	Remaining Balance
Category	**Amount Requested**	
A. Senior Personnel - *List each individual separately. Include details on how the budgeted amount was calculated. Specify Summer Pay or Release Time and the percent of effort budgeted.*		
1. PI	$18,198.00	$18,198.00
EXAMPLE: Dr. X will work 1 summer month on this project. 9-month salary is $90,000 for 9 months x 1 summer month = $10,000		
B. Other Personnel		
1. Graduate Students	$2,000.00	$2,207.00
2. Undergraduate students	$29,231.00	$29,963.00
C. Fringe Benefits		
actual rate (full time faculty)	$5,575.00	$4,862.00
9% of salary (part time staff & students)		
D. Equipment		
**only items over $5000 are considered equipment*		
E. Travel		
a. Domestic (conferences, etc.)	$3,200.00	$2,713.00
G. Other Direct Costs		
1. Materials and Supplies	$2,548.00	$2,809.00
(Note: items under $5000, such as computers, and other materials related to the activities of the project go here)		
2. Publication Costs / Documentation/Dissemination		
3. Consultant Services		
Note: if you include an external project evaluator, other individuals outside of the UT system, etc., you include them here		
4. Tuition	$2,568.00	$2,568.00
5. Subawards		
6. Other (Contractual & Special Services)	$1,680.00	$1,680.00
H. Total Direct Costs		$65,000.00
TOTAL FUNDS REQUESTED	$65,000.00	$65,000.00

THE UNIVERSITY OF TENNESSEE AT CHATTANOOGA

SIMCENTER

CENTER of EXCELLENCE in APPLIED COMPUTATIONAL SCIENCE and ENGINEERING

GRADUATE SCHOOL OF COMPUTATIONAL SCIENCE

College of Engineering and Computer Science

Final Report
July 1, 2015 – June 30, 2016

Numerical Simulation of Airflow in the Small Human Airways

Submitted to:

Tennessee Higher Education Commission Center of Excellence in Applied Computational Science and Engineering at the University of Tennessee at Chattanooga

Principal Investigators:
Dr. Abdollah (Abi) Arabshahi
Jamasp Azarnoosh
Dr. Kidambi Sreenivas
The University of Tennessee at Chattanooga
SimCenter: National Center for Computational Engineering
701 East M.L. King Boulevard
Chattanooga, TN 37403

Numerical Simulation of Airflow in the Small Human Airways

By

Dr. Abdollah(Abi)Arabshahi, Jamasp Azarnoosh and Dr. Kidambi Sreenivas

The University of Tennessee at Chattanooga, Chattanooga, TN, 37403

ABSTRACT

This study compares the effect of the extra-thoracic airways on the flow through the lower airways by carrying out computational fluid dynamics (CFD) simulations of the airflow through the human respiratory tract. In order to facilitate this comparison, two geometries were utilized. The first was a realistic nine-generation lower airway geometry derived from computed tomography (CT) images, while the second included an additional component, i.e., an idealized extra-thoracic airway (ETA) coupled with the same nine-generation CT model. Another aspect of this study focused on the impact of breathing transience on the flow field. Consequently, simulations were carried out for transient breathing in addition to peak inspiration and expiration. Physiologically-appropriate regional ventilation for two different flow rates was induced at the distal boundaries by imposing appropriate lobar specific flow rates. The scope of these simulations was limited to the modeling of tidal breathing at rest. The typical breathing rates for these cases range from 7.5 to 15 breaths per minute with a tidal volume of 0.5 Liter (L). For comparison, the flow rates for constant inspiration/expiration were selected to be identical to the peak flow rates during the transient breathing. Significant differences were observed from comparing the peak inspiration and expiration with transient breathing in the entire airway geometry. Differences were also observed for the lower airway geometry. These differences point to the fact that simulations that utilize constant inspiration or expiration may not be an appropriate approach to gain better insight into the flow patterns present in the human respiratory system. Consequently, particle trajectories derived from these flow fields might be misleading in their applicability to the human respiratory system.

1 Introduction

There are hundreds of millions of people worldwide who suffer from chronic respiratory diseases such as asthma and chronic obstructive pulmonary disorder (COPD), obstructive sleep apnea syndrome (OSAS), pulmonary hypertension, etc. (Alwan A. et al., 2008-2013). Air pollution is directly connected to these illnesses because of the deposition of particulate pollutants in the lungs. These toxic pollutant particles have the potential to induce these diseases. Particle deposition is mainly affected by the flow field within the respiratory system. These effects are very prominent in the extra-thoracic airway (ETA). An investigation reported that 80–95% of an inhaled aerosol dose is deposited in the ETA (Gonda, 1992). A detailed analysis of the airflow mechanisms within the human respiratory system could lead to a better understanding of the deposition of toxic aerosols during breathing and help with health risk assessments. Complex airflow patterns in the airways, while effective at removing inhaled toxic elements, hinder the delivery of therapeutic materials delivered through inspiration. Over the past 20 years, computational fluid dynamics (CFD) has been established as a powerful tool for the study of these complex flow patterns and its application to improvements in aerosolized medication delivery. Even with these advances, the complex flow patterns in these airways are still understood only at a relatively rudimentary level.

2 Literature Review

The flow through the human respiratory tract has been studied extensively, both experimentally and via numerical simulations. Studies regarding the lower airways typically use a laminar profile at the trachea, which is the point of delineation between the ETA and the lower airways. However, various studies conducted using ETA models, have clearly shown that the flow exiting the ETA is very likely turbulent. The inherent complexity of flows through the ETA can lead to regions which are laminar, transitional or fully turbulent. Attempts to study flows (experimental or computational) through the ETA are stymied because of the wide variability in ETA geometries depending on age, disease, etc. One approach to the problem of variability is to create an idealized ETA geometry which contains all the basic physiological elements that are present in the real geometry. (Yu et al., 1998) used a teaching model as the basis of the geometry for the ETA while (Stapleton et al., 2000) utilized an idealized version of an ETA based on CT scans. The so called Alberta ETA geometry (Johnstone et al., 2004) has been studied extensively using both experimental (Heenan et al., 2003), (Johnstone et al., 2004) and computational (Ball et al., 2008a, b) approaches. Ball et al. (Ball et al. 2008a) used various turbulence models to simulate the flow through this geometry and compared their results to experimental data. They (Ball et al., 2008b) also used a Lattice Boltzmann method (LBM) to study the details of the flow field while Kleinstreuer and Zhang (Kleinstreuer, C., & Zhang, Z., 2010) used an LES approach.

The framework for the study of the airflow through the lung and human pulmonary airways was laid by (Weibel, 1963) and (Horsfield et al., 1971). Xu et al. (Xu et al., 2006) simulated constant inspiration and expiration of the airflow through a CT-based geometry. De Backer et al. (De Backer et al., 2008) carried out numerical simulation of constant inspiration through CT-based lower airways. Lin et al. (Lin et al., 2007) compared the effects of an ETA by simulating the flow through a CT-derived model of the upper respiratory tract and the lower airways with the corresponding the lower airway geometry only. They concluded that a curved sheet-like turbulent laryngeal jet in the entire airway geometry, with turbulence intensity exceeding 10 to 20% in the trachea, could significantly affect airway flow patterns as well as tracheal wall shear stress. These simulations were limited to constant inspiration only. In an earlier study, the effects of inhalation transience through CT-based human airway geometry were explored by Gruetzemacher (Gruetzemacher, 2014), where he obtained solutions for a full breathing cycle. As is the norm in these types of simulations, a uniform velocity profile was imposed at the trachea (for the constant inspiration case) and lobar specific flow rates were imposed at the distal airways (for the full breathing cycle). An interested reader directed to Gruetzemacher (Gruetzemacher, 2014) for more details.

Numerical studies provide detailed information of airflow patterns that is very difficult to obtain using in vivo observations or in vitro experiments. Earlier studies had mostly focused on constant inspiration, although some of them did consider a full breathing cycle or constant expiration. The geometries utilized in most of these studies were limited to either the ETA or the lower airway only. For instance, (Zhang, Z., & Kleinstreuer, C., 2002) compared both the peak inspiration and expiration velocity profiles for the Womersley number ( ) 0.93 and found good agreement with those of instantaneously equivalent constant inspiration/expiration cases. This paper focuses on the effects of the ETA on the lower airway (and vice versa) for a full breathing cycle and compares the results of transient simulations with simulations corresponding to constant inspiration and expiration. To the best of the authors' knowledge, these comparisons have not been carried out, by any researcher, for the entire (combined ETA/lower) geometry.

3 Methods

3.1 The idealized ETA and CT-based pulmonary airway geometry

The computational ETA geometry utilized in this study is based on the so-called Alberta ETA model from University of Alberta. This geometry represents a mean of the dimensions of the upper airway which mimics the complete ETA from the oral cavity to the trachea of an adult human. The overall height (including the inlet nozzle) and width of this geometry are 160.4 and 110 mm, respectively. Licensing issues prevented the actual geometry from being used in this paper. The geometry utilized in this study has been reconstructed based on the descriptions and cross-sections available in the literature, for instance, (Heenan et al., 2003), (Johnstone et al., 2004) and (Zhang, Y., & Finlay, W. H., 2005). The geometry was created using SolidWorks, a 3D Computer Aided Design (CAD) modeling package. Figure 1 shows the dimensions and the anatomical names which include the most important airflow structures in the sagittal plane of the ETA. Traverse cross-sectional views of the airway passage of all thirteen cross-sections are depicted in Figure 1c.

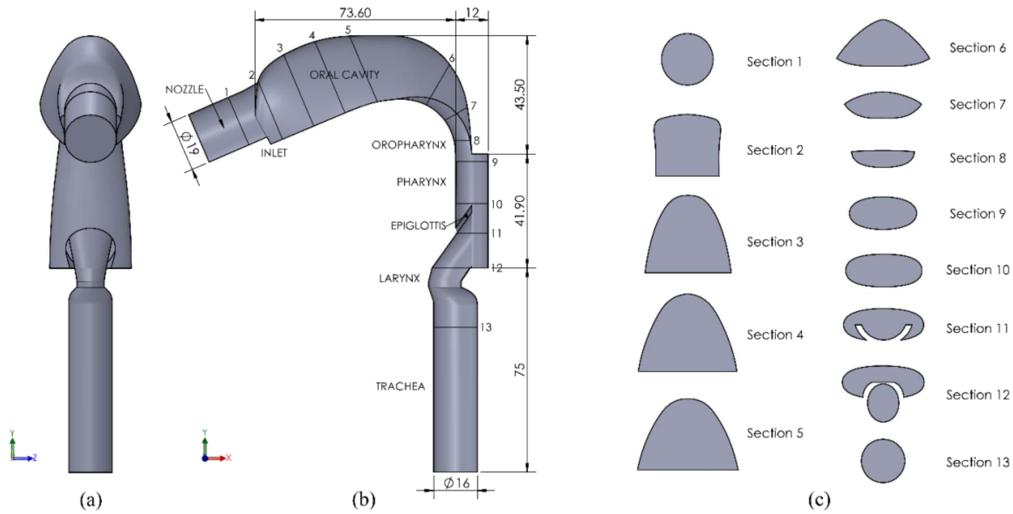


Figure 1. The idealized ETA geometry: (a) Coronal view (b) Sagittal cross section view with dimensions (c) Traverse cross sectional views of the airway passages.

The various regions of the ETA are geometrically very different which is revealed in the complexity of the model. The oral cavity features different radii of curvature along the sagittal and coronal (frontal) planes. In the posterior of the oral cavity, the cross sectional shape converges to a somewhat half elliptical shape, and is then extended by the uvula. The shape remains elliptical within the pharynx before the glottal region. The epiglottis protrudes into the pharynx volume, thus the airflow must travel around it before entering the trachea and then on to the main bronchi and subsequently the lungs.

As can be seen from Figure 1, the local area increases from the inlet to the oral cavity and then decreases through the oro-pharynx (cross-sections 2-8). There is a sudden change in the local area from oro-pharynx to pharynx (cross-sections 8-9). Thus, the bulk velocity decreases, consequently reducing the Reynolds number. The existence of epiglottis (cross-sections 11 and 12) in the pharynx causes this region of the model to be more complicated.

The ETA geometry was scaled to match with the CT-based lower airways model of Gruetzmacher (Figure 2a) to provide the entire airway geometry (Figure 2b and c).

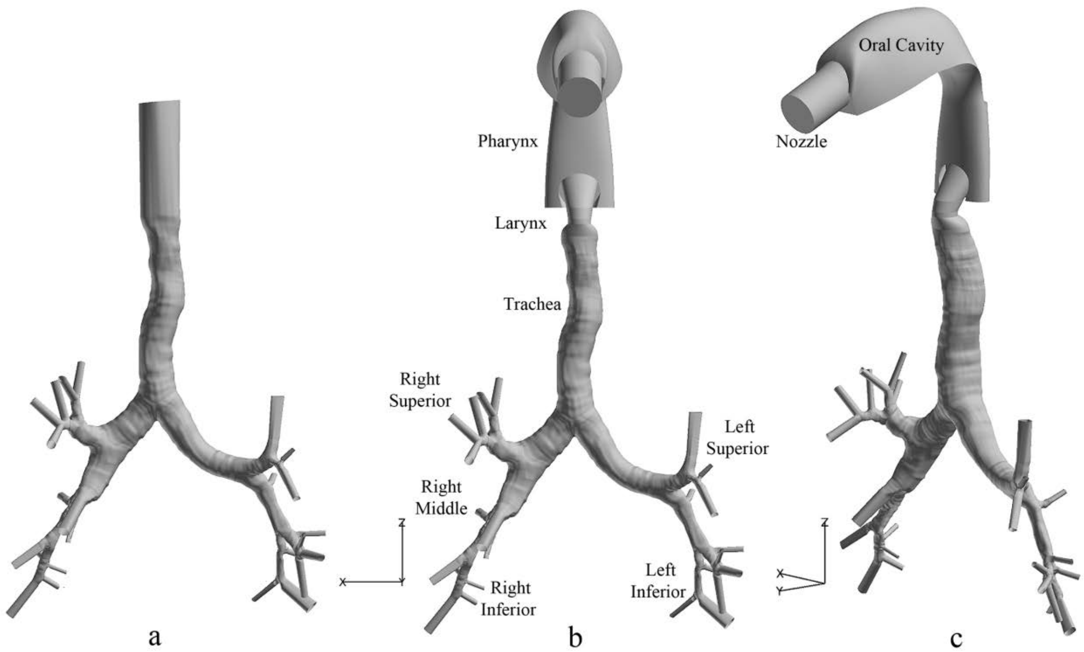


Figure 2. a) The CT-based lower airway geometry. b and c) The entire airway geometry

Both geometries were meshed using Pointwise version 17.3. The surface mesh was entirely structured, as this helped reduce the number of surface nodes compared to utilizing an unstructured surface mesh. The volume mesh was generated using an off-wall spacing ranging from 0.01 to 0.05 mm such that an average y^+ of around unity was obtained. The volume mesh utilized the T-Rex feature of Pointwise (T-Rex: Automated Boundary Layer Meshing, 2010). This resulted in the extrusion of regular layers of tetrahedra from boundaries, which are recombined to obtain prism elements off the walls. A minimum of 7 prism layers were utilized in this study. Two different meshes were generated for the entire airway geometry. The different meshes were generated so as to maintain adequate viscous resolution for the two different flow rates considered in this study. The first mesh (low flow rate) contained 7,886,440 nodes and 31,157,333 control volumes while the mesh for the high flow rate had 8,491,553 nodes and 32,788,751 control volumes. In order to assess the impact of the ETA on the flow through the lower airways, a mesh for the lower airways was also generated. This mesh contained 3,142,780 nodes and 18,035,344 control volumes.

3.2 Flow solver

The in-house flow solver, *Tenasi* (Hyams et al., 2011) was used in this study to simulate both inspiration/expiration and a full respiratory cycle. The baseline flow solver in *Tenasi* employs a node centered, finite volume, implicit scheme with high resolution fluxes based on Roe averaging and a Newton subiteration procedure for time accuracy. The linear system at each Newton subiteration is solved using a Symmetric Gauss–Seidel algorithm. For the cases considered here, *Tenasi* solves the artificial-compressibility form of the incompressible Navier-Stokes equations. *Tenasi* has been validated in a previous study for steady and unsteady flow through idealized and CT-based geometries (Gruetzemacher, 2014). LES is sufficient to resolve the large-scale eddies of turbulent flow without using any turbulence model, however, this is inappropriate to resolve smaller scales of turbulent motions i.e. length scales smaller than the grid spacing. Therefore, these small unresolved length scales are modeled by a SGS turbulence model. In this study, the Wall-Adapting Local Eddy-viscosity (WALE) model (Ducros et al., 1998) is used for the SGS stresses. The SGS tensor is given by

(1)

Subgrid scale modeling is based upon an eddy-viscosity assumption. The eddy viscosity model is defined as

(2)

where . Note that the over-bar denotes a time-average.

The eddy viscosity appearing in the SGS term of the WALE model) is defined as

(3)

where , , for incompressible flow and .

This model was used because it resulted in good predictions of the wall stress and turbulent intensities as reported by Ducros et al., 1998.

To investigate turbulent characteristic of the flow, the turbulence kinetic energy (TKE) and turbulence intensity were used. The TKE can quantified by the mean of the turbulence normal stresses which is defined as

(4)

For steady laminar flow TKE is zero while the large value of TKE represents the existence of the turbulent flow phenomena.

The turbulence intensity is

(5)

where .

The cases presented here are solved using a Large Eddy Simulation (LES) formulation with the Wall-Adapting Local Eddy-viscosity (WALE) model (Ducros et al., 1998) being used for the subgrid stresses.

3.3 Numerical Solution

The computations utilized a quadratic reconstruction approach, and were solved in unsteady (time-accurate) mode utilizing 80 Newton subiterations to ensure second order temporal accuracy. Dual-time-stepping was used to enhance stability of the iterative solution process with a Courant-Friedrichs-Lewy (CFL) number in the range of 0.015 to 0.025.

Two breathing rates (7.5 and 15 breaths per minute) corresponding to the range of typical human breathing at rest were considered in this study. The transient breathing cases were simulated for one breathing cycle and utilized 7,968 iterations resulting in different time steps ( ). Table 1 summarizes the various parameters that were used in these simulations. The Womersley number (Womersley, 1955) shown in the table is the ratio of the transient inertial force to the viscous force and is a significant nondimensional parameter in the study of transient flows. It is defined as , where R is the radius of the trachea, the kinematic viscosity and where is the breathing rate. The Reynolds number is defined as , where D is the average diameter of the trachea and is largest of the velocities imposed at the distal boundaries.

The constant inspiration and expiration simulations corresponded to the peak inspiration and expiration for the two breathing rates considered here (hereinafter referred to as). They were carried out for 8,000 iterations and the resulting solutions were time-averaged over the last 3,000 time steps.

Table 1: Parameters for the breathing cycles considered in this study

Breathing Rate		Re	(seconds)	T (seconds)
7.5 breaths/minute	4.72	875		8
15 breaths/minute	6.68	1750		4

3.4 Boundary conditions

Humans have two lungs which consist of five lobes. Three lobes on the right and two on the left, i.e., right superior (RS), right middle (RM), right inferior (RI), left superior (LS), and left inferior (LI) bronchus. For the transient breathing cases, a sinusoidal waveform velocity profile was imposed at the distal lobar boundaries, i.e., , while the pressure was allowed to float. To enforce the appropriate velocities at lobar boundaries an expression for velocity as a function of the lobar volume was written (Gruetzemacher, 2014), i.e., , where is area at the appropriate distal boundary and is 0.105, 0.045, 0.125, 0.1 and 0.125L corresponding to the RS, RM, RI, LS and LI, respectively (Horsfield et al., 1971). The velocity used for the inspiration/expiration cases matched the flow conditions at peak inspiration and expiration of the transient breathing cases, i.e. at phase angle of and , respectively. At the inlet boundary, a pure Dirichlet boundary condition was used to keep static pressure fixed at standard atmospheric pressure while the velocities were allowed to float.

4 Results and Discussion

A discussion of the results obtained for the geometries are presented in thi section. Firstly, the ETA geometry was validated with experimental data and computational (LBM) simulation for a flow rate of 10 l/min using the SST turbulence model and LES which resulted in four simulations, i.e., simulations for coarse and fine mesh for each technique. A comparison of constant inspiration/expiration with the first transient breathing cycle was carried out for each flow rate. Two LES simulations were performed for 30 l/min so that a comparison between the two flow rates could be carried out. Similarly, the simulations of the entire airway geometry are presented for constant inspiration/expiration and full transient breathing cycles resulted in six simulations.

4.1 The Idealized Upper Airway Geometry (the ETA geometry)

The comparison of LES simulation with PIV data and LBM is presented in the first part of the simulation of the ETA geometry. The local coordinate system used here is the same as the one used by Johnstone et al. and Ball et al. (Dubief, Y., & Delcayre, F., 2000). As depicted in Figure 3, the coordinate system is defined in the sagittal plane. x is defined along the direction of the probe, y is perpendicular to the x-direction (in the direction of the flow) and z is perpendicular to the sagittal plane. The origin of the coordinate system is on the superior (inlet and cross-sections 1 to 4) or posterior wall (cross-sections 5 to 7) in the sagittal plane of the ETA (Figure 4). Note that these cross-sections are the measuring locations that were used by Johnstone et al.

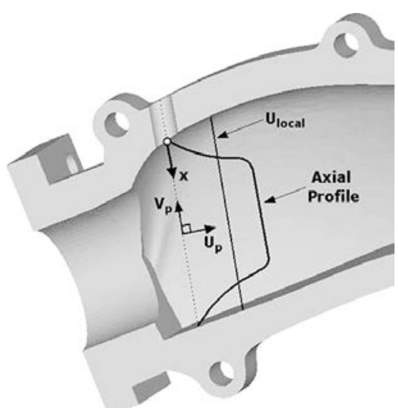


Figure 3. Local coordinate systems from Johnstone et al. (2004)

As mentioned before, the geometry utilized in this study is not the original geometry and has been reconstructed based on available papers in the literature. Therefore, some deviations from the geometry used in the experiments can be expected. The investigation was carried out by comparing the results of the LES simulation with hot-wire anemometry data (Heenan AF, Matida E, Pollard A, Finlay W.H., 2003), as well as direct numerical simulation i.e., LBM (Ball, C. G., Uddin, M., & Pollard, A., 2008b), at seven cross-sections (see Figure 4) for the flow rate 10 l/min.

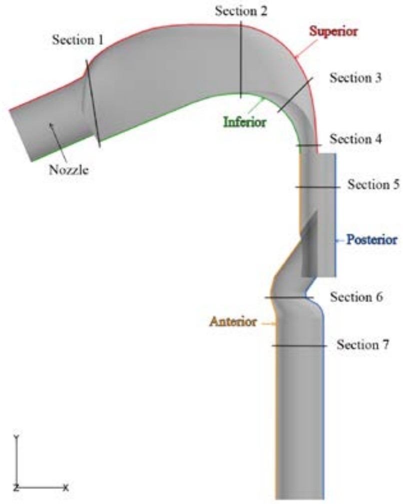


Figure 4. Seven traverse cross-sections illustrated in sagittal plane of the ETA

Simulations were carried out for two grids (coarse and fine gird as summarized in Table 2), but for comparison solutions of the coarse mesh were utilized, because no significant differences were observed between these two grids.

Table 2. Number of nodes and volume elements of all grids

Geometry		Low flow rate		High flow rate	
		Nodes	Number of volume elements	Nodes	Number of volume elements
The upper airway	Coarse	4,990,450	12,979,034	5,110,5590	13,559,688
	Fine	9,744,653	25,520,582	10,059,168	27,399,523
The lower airway		3,142,780	18,035,344	3,142,780	18,035,344
The entire airway		7,886,440	31,157,333	8,491,553	32,788,751

The contour plot of the time-averaged LES solution in central sagittal plane for flow rates of 10 and 30 l/min are shown in Figure 5. Generally, the same structure of the flow can be observed for both flow rates. The difference is in the strength of the flow that is clearly visible in the length of laryngeal jet within the trachea. Therefore, the comparisons of time-averaged velocity profiles and flow structures through the ETA with experimental and computational results (LBM solutions) were carried out only for 10 l/min.

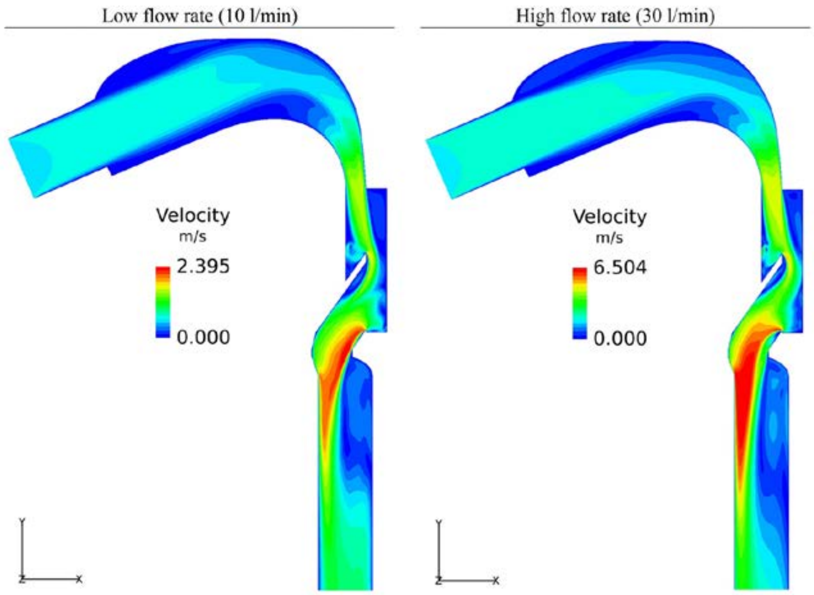


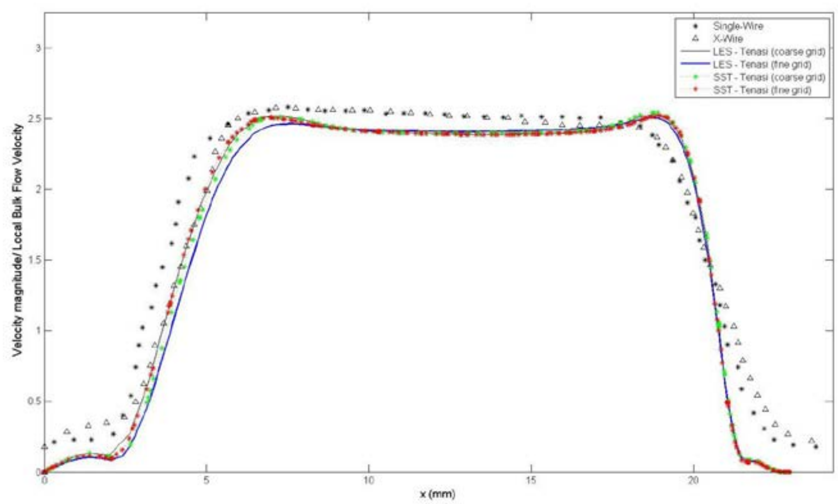
Figure 5. Contour plot of the central sagittal plane of the ETA, colored with the velocity magnitude, for flow rate 10 and 30 l/min

The values of the local Reynolds number, i.e. , and local bulk velocities at the inlet and all seven cross-sections (see Figure 4) were compared against the PIV [4] and LBM (Ball, C. G., Uddin, M., & Pollard, A., 2008b) in Table 3. The most differences of the local Reynolds number can be found at cross-section 2 and 5 with 8% and cross-section 6 with 10.5%. This shows a reasonable agreement of the reconstructed geometry with the original experimental geometry.

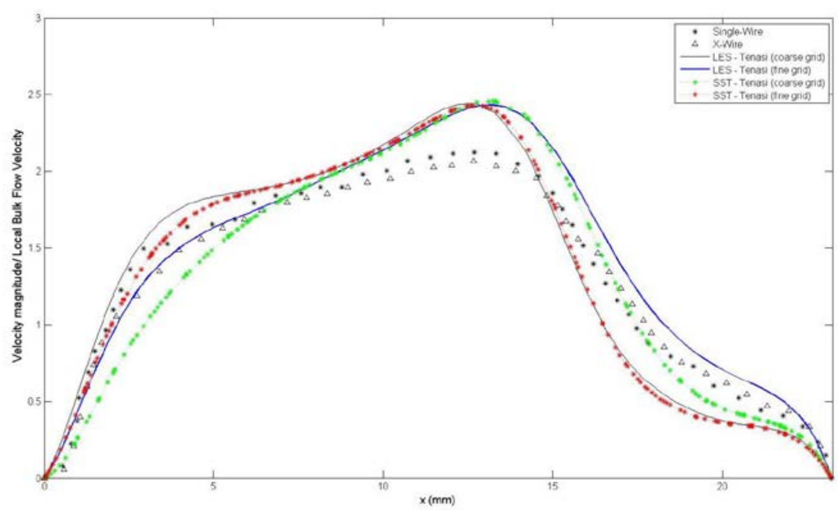
Table 3. Comparison of the local Reynolds number and local bulk velocity between PIV data, the LBM and LES solutions at the inlet and seven cross-sections

Sections	PIV results (Johnstone et al.)	LBM solution (Ball et al.)		LES solution (Coarse mesh)	
	Re		Re		Re
Inlet	674	0.587	677	0.58632	675.474
1	483	0.291	477	0.31851	518.922
2	480	0.275	464	0.31151	522.217
3	716	0.542	651	0.55048	688.477
4	1052	1.178	960	1.35403	988.884
5	699	0.623	698	0.68282	758.9313
6	1073	1.368	1034	1.61969	1198.337
7	805	0.778	780	0.85325	827.9199

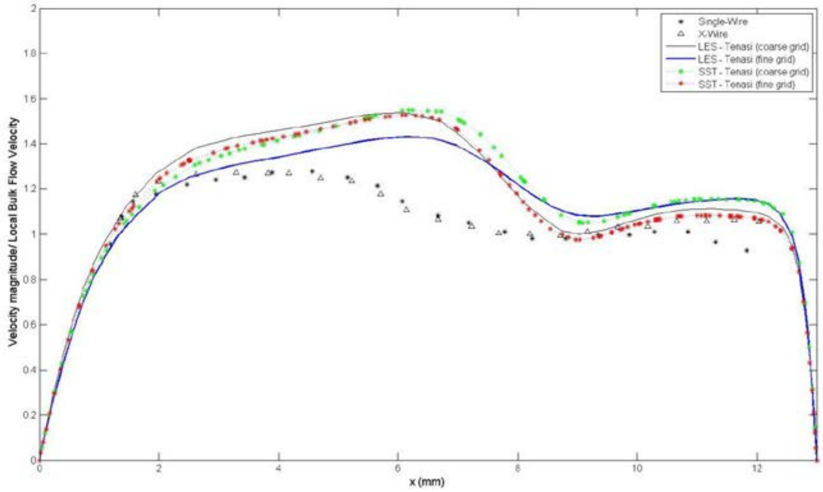
Figure 6 illustrate the comparison of SST and LES solutions of coarse and fine mesh from *Tenasi* along with experimental results for flow rate 10 l/min. The overall agreement between the various solutions is quite similar, though there are some significant differences. For cross-section 2, the fine grid LES solution has much better agreement with experimental data than either the coarse grid LES or both the SST solutions, though all the solutions over predict the peak velocity at that cross-section. Overall, the fine grid LES solution has better agreement with the experimental data, while the sensitivity of the RANS (SST) solutions to grid density does not seem to be that high.



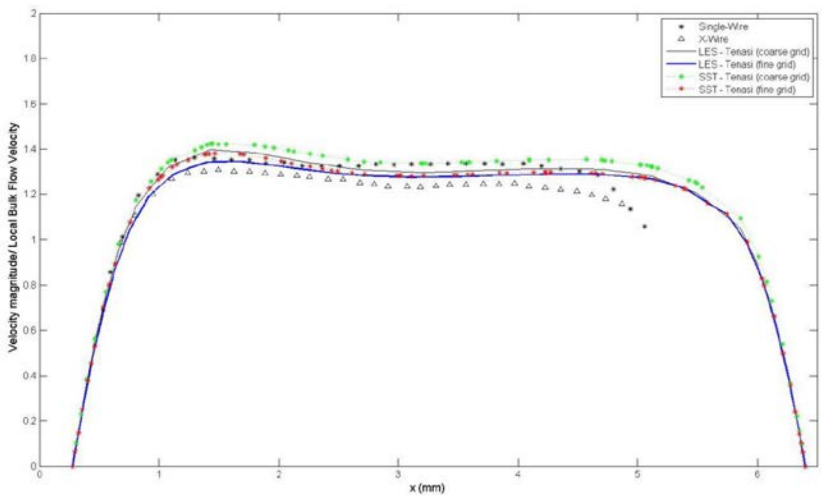
Cross-Sections 1



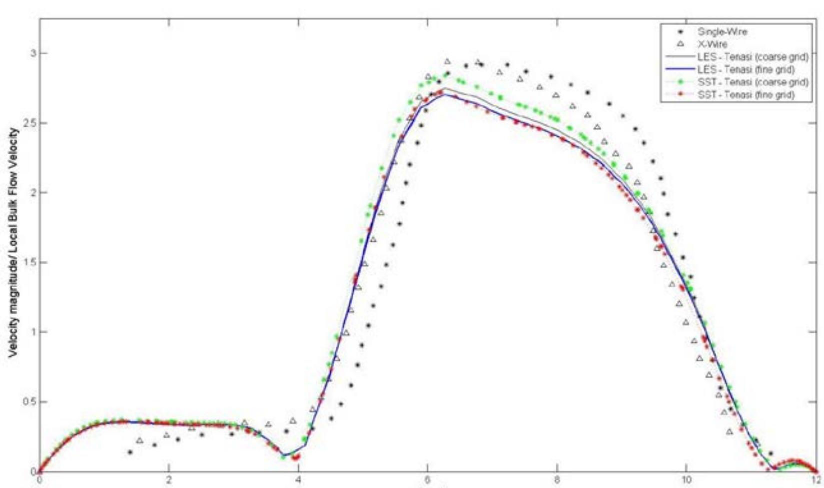
Cross-Sections 2



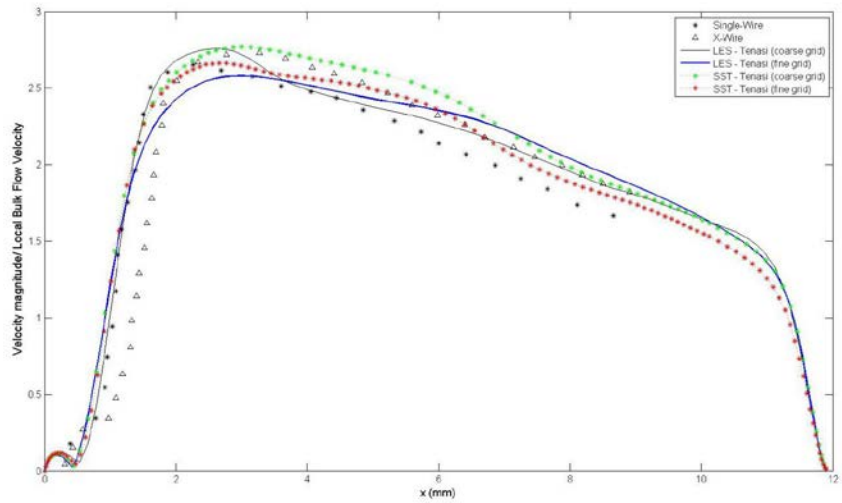
Cross-Sections 3



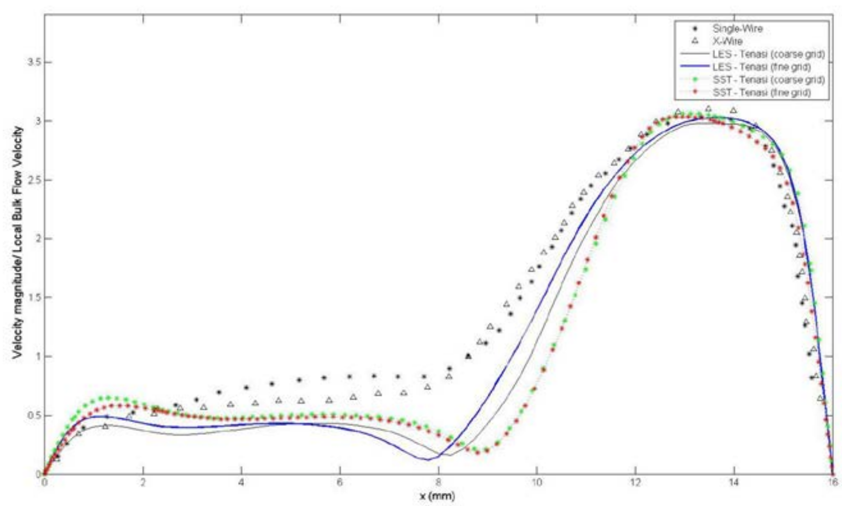
Cross-Sections 4



Cross-Sections 5



Cross-Sections 6



Cross-Sections 7

Figure 6. Comparison of SST and LES solutions of coarse and fine mesh from *Tenasi* with experimental results from Johnstone et al. at cross-sections 1-7

4.2 Transient Breathing Cycle and Constant Inspiration/Expiration

Simulations of the ETA geometry were performed for two flow rates summarized Table 4. Two simulations corresponding to constant inspiration/expiration and one for four full breathing cycles were carried out. This resulted in a total of three simulations per flow rate. The constant inspiration/expiration cases were conducted at two Reynolds numbers, i.e., 875 and 1750, analogous to peak flow conditions in the full breathing cases, i.e., the Womersley numbers of 4.72 and 6.68, respectively.

4.2.1 Inspiration

Peak inspiration in a breathing cycle solutions occurs at a phase angle of at t = 2s and t = 1s for and , respectively. The comparison was made between peak inspiration with corresponding constant inspiration for both flow rates (i.e., Re = 875 and Re = 1750). Volumetric fluxes were computed at the inlet and outlet of the ETA. The deviation of flow rates from the targeted values was found no more than 0.05%.

The flow structure of a transient breathing cycle in both flow rates is depicted against the time-averaged solution in the central sagittal plane of the ETA in Figure 7. Even though the flow features in the oral cavity as well as the oro-pharynx are observed to be laminar, unsteadiness can be seen in the transient breathing cases for both flow rates, especially for the higher flow rate where unsteadiness was much more pronounced. This figure shows that the flow rate is not the main cause of the turbulent flow through the trachea. Because of the Dean-like instabilities caused by the curvature of the oro-pharynx, and the complicated structure of the pharynx and the larynx, the airflow became transitional and eventually fully turbulent through the trachea. Fully turbulent flows in both flow rates are clearly visible in the figures.

From the time-averaged solutions the same flow pattern was observed in both flow rates. The only difference is in the strength of the airflow as the velocity values doubled for the higher flow rate. This is clearly visible in the laryngeal jet and the size of the recirculation bubble in the trachea.

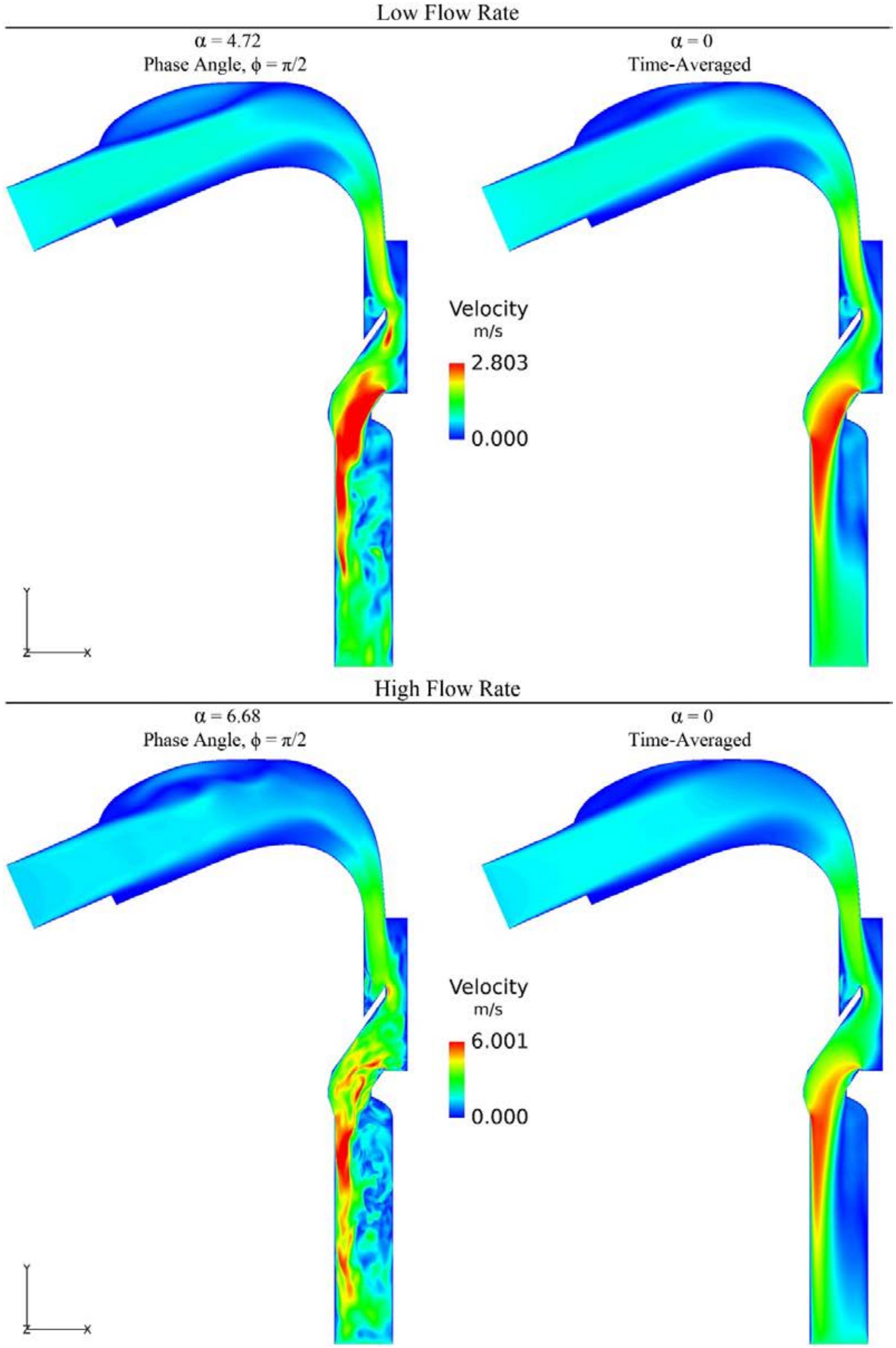


Figure 7. Central sagittal cross-section of the ETA, illustrating velocity magnitude during inspiration. Peak transient breathing and time-averaged solutions of both flow rates

The secondary flow at three cross-sections of the ETA (see Figure 4) is illustrated in Figure 8, to have a better insight into the flow regime during inspiration. Cross-sections 5, 6 and 7 were selected because significant changes in the flow features occur through the pharynx, the larynx and more importantly the trachea. The comparison of these three critical cross-sections between transient breathing and constant inspiration are discussed in the following.

Cross-section 5 is located in the pharynx (see Figure 4) upstream of the larynx. Clear differences can be observed in the cross-flow pattern between transient breathing and the time-averaged solution of both flow rates. Unsteadiness in the high flow rate case was much more pronounced compared to the low flow rate. This shows the effects of the flow rate in this region. Transient solution of the high flow rate illustrated strong unsteadiness of the flow pattern in the oro-pharynx, before entering the pharynx. As was previously mentioned, this is due to the Dean-type instabilities in oro-pharynx.

The complicated flow regime in the pharynx causes the flow to be turbulent in the larynx and consequently in the trachea. The presence of the turbulent flow is clearly visible in iso-surface of Q-criterion in Figure 9. Unsteadiness in both transient breathing solutions can be observed at cross-section 6. In this location, the turbulent feature is clearly visible in the transient breathing solution of the high flow rate, whereas the low flow rate shows less turbulent features.

The cross-section in the trachea, cross-section 7, illustrates the fully turbulent flow for both the low and high flow rates. This highly turbulent flow phenomenon is much more prominent for the higher flow rates. Figure 9 illustrates this flow phenomenon through the larynx and the trachea.

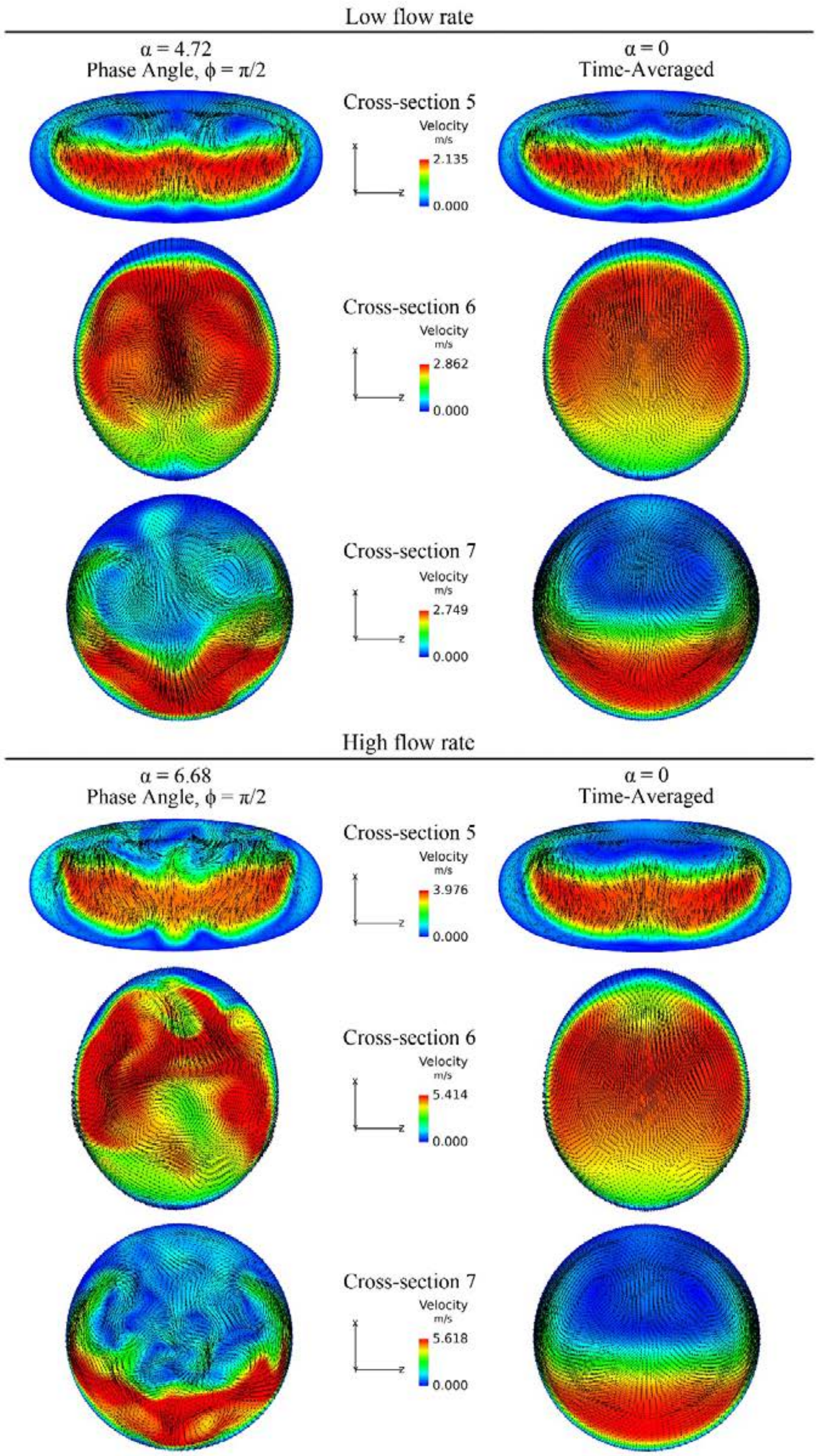


Figure 8. Secondary flows of the low and the high flow rate during inspiration in the ETA. Cross-sections 5, 6 and 7 of the low and high flow rates from the top and bottom, respectively

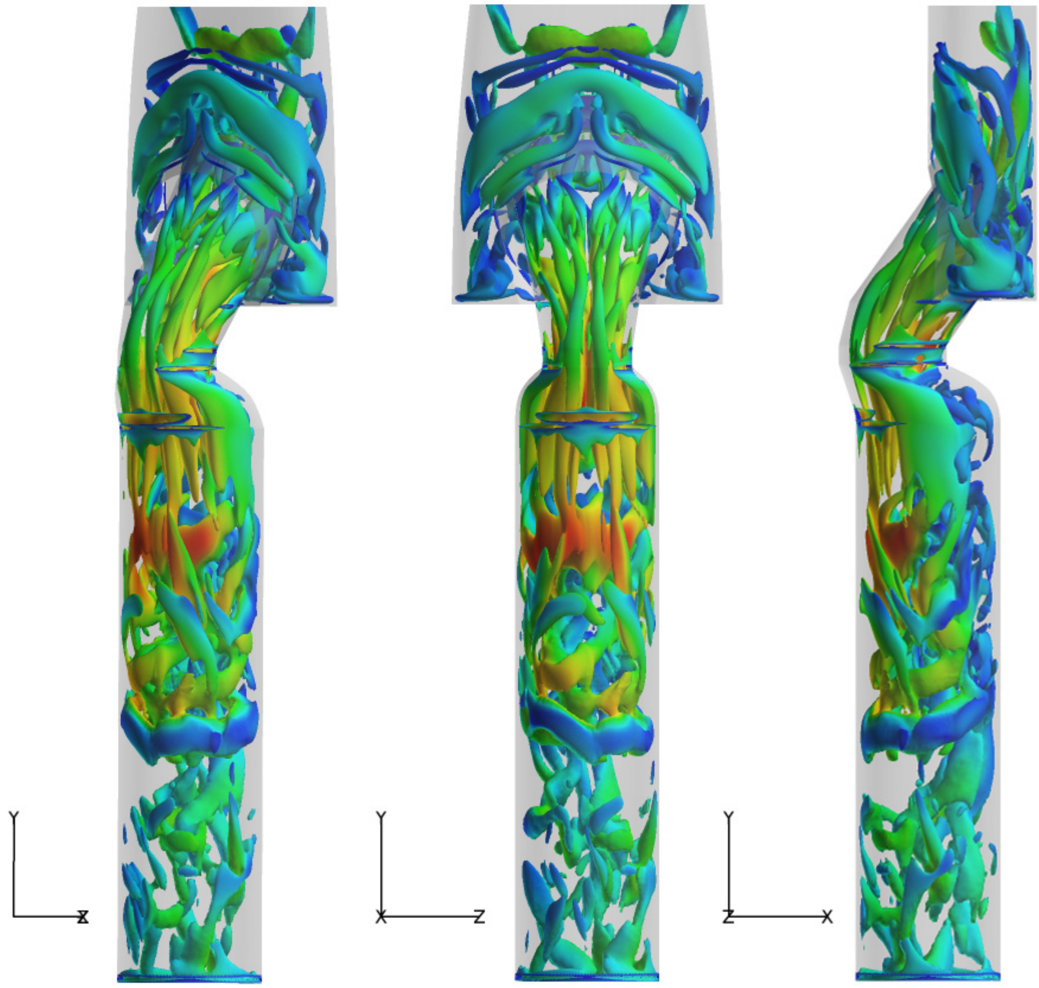


Figure 9. Iso-surface of Q-criterion colored by velocity magnitude for .
Oblique (45) view, coronal view and sagittal view of the pharynx and larynx from left to right. The geometry is in gray

The values of the Reynolds number at all seven cross-sections of interest in Figue 4 are summarized in Table 4. The largest differences between Reynolds numbers for the constant inspiration and peak transient breathing for the low Womersley number was found to be no more than 4% and appeared at cross-section 7. As the flow rate is doubled i.e., higher Womersley number, the differences of the Reynolds numbers are almost doubled as well. Similarly, cross-section 7 has the highest discrepancy in Reynolds number with approximately 8.8% for higher Womersley number.

Cross-section 6 has the highest value of Reynolds number in both flow rates among all the cross-sections considered here. This illustrates the effects of complexity of the geometry on the flow field in this region.

Table 4. Reynolds numbers of constant and transient breathing cycle during inspiration at all seven traverse cross-sections of the ETA

Sections	Low flow rate		High flow rate	
	Re (Constant inspiration)	Re (Transient breathing)	Re (Constant inspiration)	Re (Transient breathing)
1	713.597	728.061	1382.267	1335.218
2	733.432	736.446	1430.346	1355.901
3	964.419	956.027	1875.775	1761.193
4	1438.58	1423.414	2812.341	2711.333
5	1121.371	1127.912	2192.301	2291.231
6	1617.872	1665.383	3164.647	3122.832
7	1284.596	1338.778	2396.159	2628.476

4.2.2 Expiration

Peak expiration in breathing cycle solutions occurs at a phase angle at and for and , respectively. The comparison was made between peak expiration with corresponding constant expiration for both flow rates (i.e. Re = 875 and Re = 1750).

Velocity contour plot of the central sagittal plane of the ETA during expiration for both flow rates are displayed in Figure 10. Similar to inspiration, the flow pattern of the time-averaged solution of both flow rates is approximately identical; the only difference is in the strength of the flow. The third backward facing step during inspiration has a role of a forward facing step during expiration. As with inspiration, the jet-like flow was formed in the opposite direction during expiration. A small recirculation zone appeared at posterior wall of trachea. Unsteadiness in jet-flow was observed in transient breathing of both flow rates. These effects are more significant for higher flow rate. Critical changes in the flow regime occurred right after jet-flow in the larynx. For both flow rates, the flow is unsteady and highly three-dimensional.

Cross-sections 2, 3, 4 and 5 were considered for investigation of the flow structure during expiration. These locations were selected to have a better understanding of the flow phenomena in the pharynx and the oral cavity. As can be seen in the central sagittal plane of both flow rates in Figure 10, fully turbulent flow is clearly visible in the pharynx, oro-pharynx and consequently in the oral cavity. Secondary flows at the four cross-sectional planes of interest in the ETA are shown in Figure 11. The flow pattern of the time-averaged solutions of the low and the high flow rates are approximately similar at each cross-section. Again, the difference is in the strength of the flow. The flow pattern of transient breathing solutions at all these four cross-sections shows the presence of the turbulent flow in both flow rates. This can also be seen in the iso-surface of the Q-criterion of the low flow rate in Figure 12. This reveals that the flow regime during expiration is much more complicated than inspiration with high level of turbulent flow in the pharynx and the oral cavity.

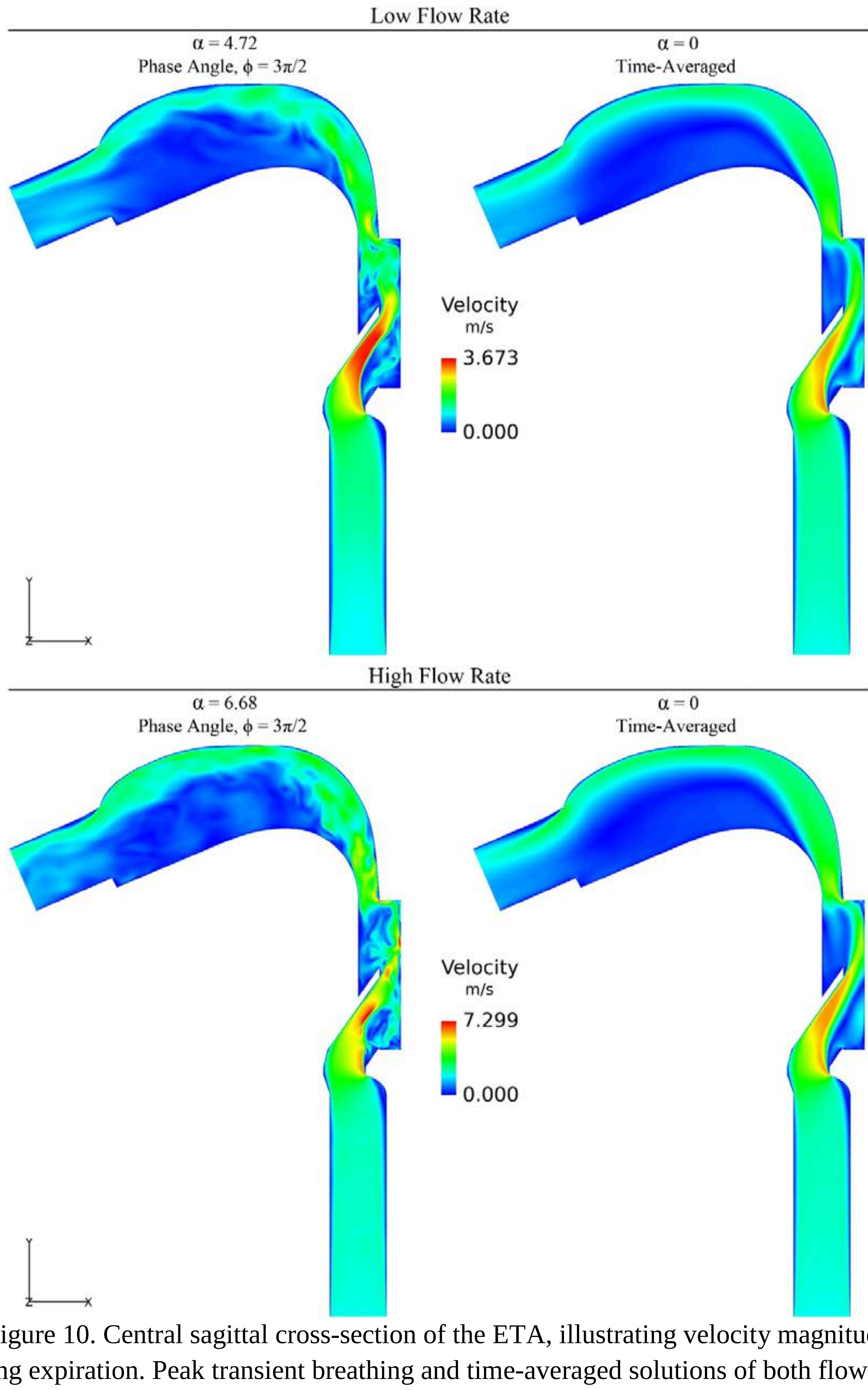


Figure 10. Central sagittal cross-section of the ETA, illustrating velocity magnitude during expiration. Peak transient breathing and time-averaged solutions of both flow rates

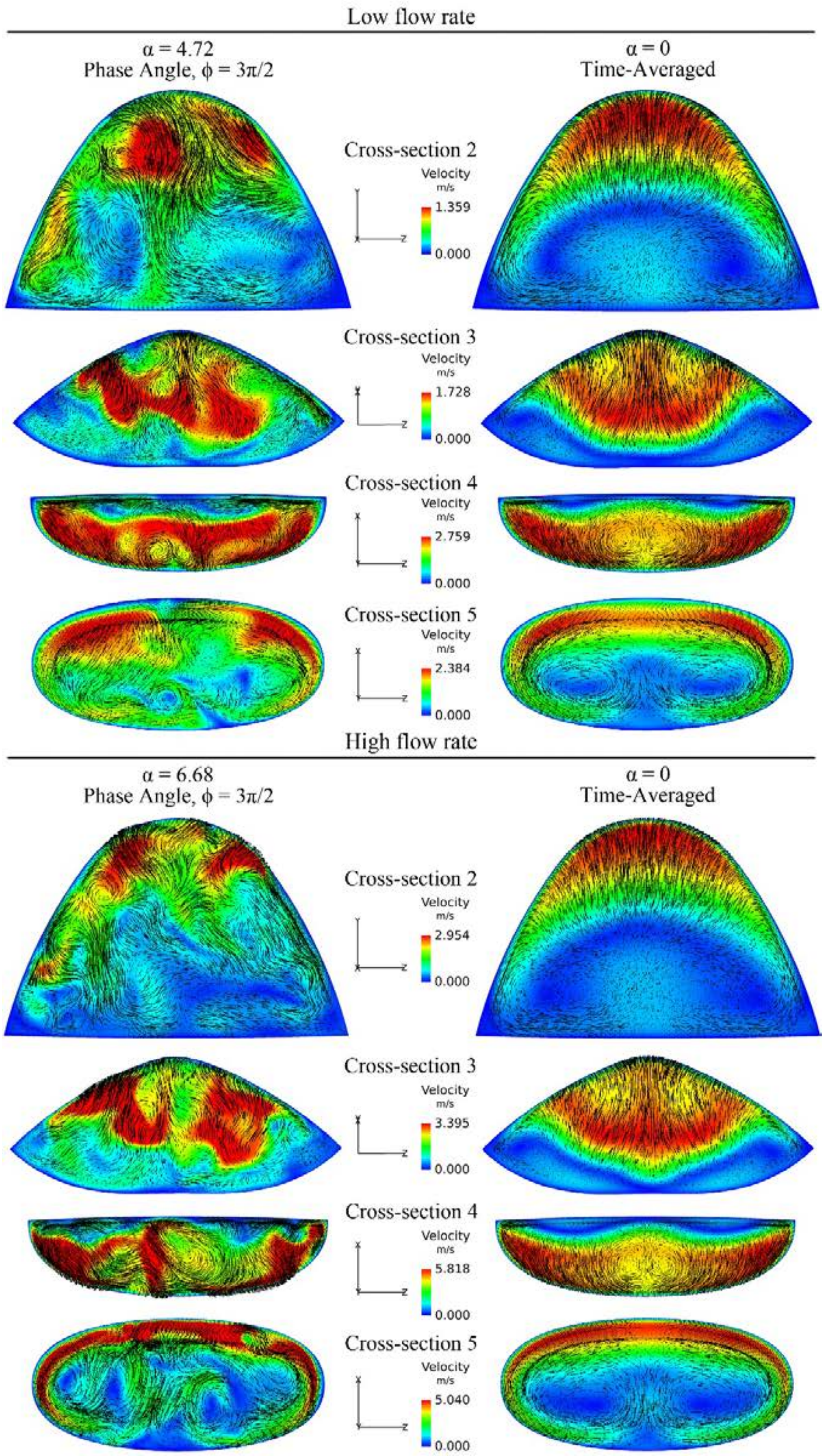


Figure 11. Secondary flows of the low and the high flow rate during expiration in the ETA. Cross-sections 5, 6 and 7 of the low and high flow rates from the top and bottom, respectively

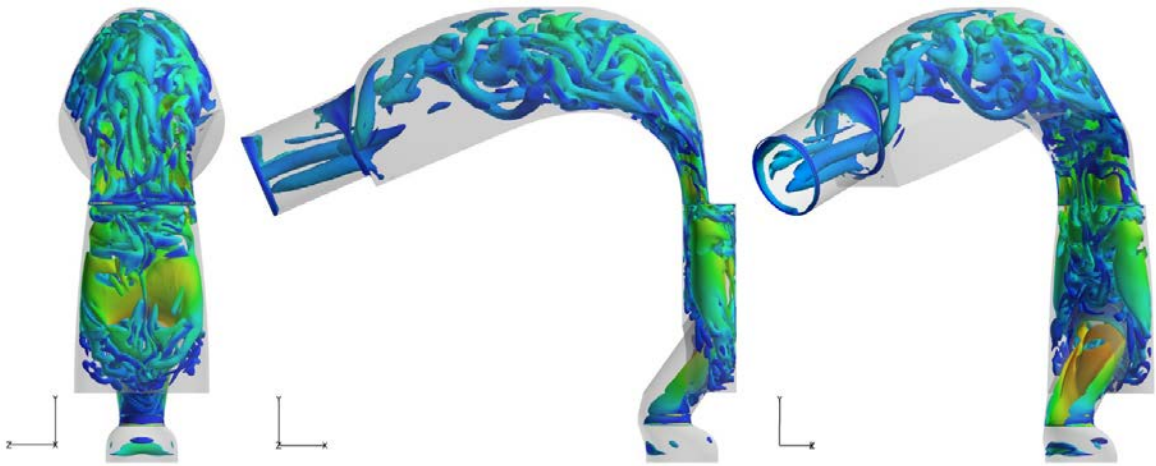


Figure 12. Iso-surface of Q-criterion colored by velocity magnitude for during expiration. Back view, sagittal view and right oblique (45) of the ETA and the trachea from left to right. The geometry is in gray

The values of the Reynolds number for both flow rates during expiration are summarized at all seven cross-sections in Table 5. Reynolds numbers in either flow rates suggested higher values at all locations, except cross-section 7, compared to inspiration in Table 4. This confirms the earlier statement about the complexity of the flow during expiration. In both flow rates, significant differences of Reynolds number between transient breathing and constant expiration can be observed in many cross-sections, especially at locations 2 and 5. Highly turbulent flow was found through the pharynx, oro-pharynx and the oral cavity. Hence, discrepancies of the Reynolds numbers are not surprising at these locations.

Table 5. Reynolds numbers of constant and transient breathing cycle during expiration at all seven traverse cross-sections of the ETA

Sections	Low flow rate		High flow rate	
	Re (Constant expiration)	Re (Transient breathing)	Re (Constant expiration)	Re (Transient breathing)
1	945.102	1043.254	2219.366	2022.078
2	895.443	1089.182	1738.081	1956.892
3	1100.579	1196.479	2331.001	2441.723
4	1482.123	1589.581	2957.619	3204.702
5	1276.371	1594.169	2402.271	2726.444
6	1641.512	1604.205	3233.819	3115.181
7	1077.172	1156.734	2113.241	2076.269

4.3 The Entire Airway Geometry

Final simulations were carried out for the entire airway geometry in addition to the lower airways geometry. For each flow rate, two simulations (constant inspiration and expiration) and one full breathing cycle simulation were carried out. This resulted in 6 simulations per flow rate and a total of 12 simulations. The constant inspiration/expiration cases were conducted at two Reynolds numbers, i.e., 875 and 1750, analogous to peak flow conditions in the full breathing cases, i.e., the Womersley numbers of 4.72 and 6.68, respectively. Five cross-sections of interest in the lower airways, shown in Figure 7, were selected for analysis. These cross-sections are representative of the airflow entering each lobar bronchus. Volumetric fluxes were computed at each of the cross-sections. The deviation of flow rates from the targeted values were found no more than 0.045% and 2% in lower airways and the entire airway geometry, respectively.

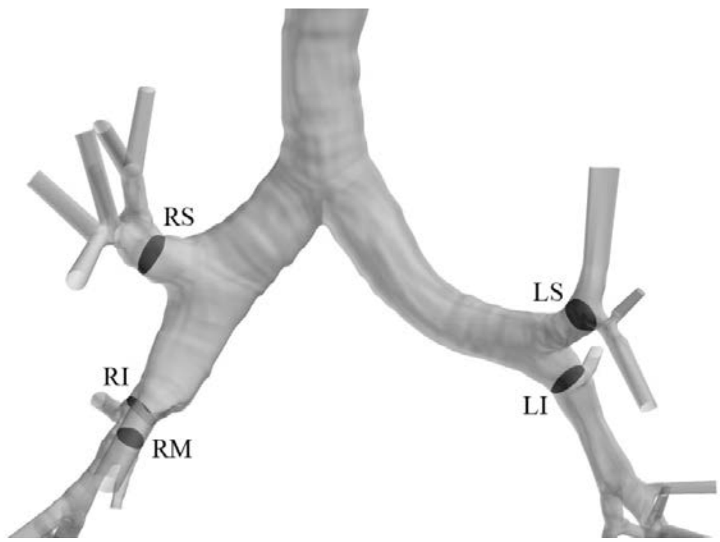


Figure 13. Five cross-sections examined for each case at each of the lobar bronchus

4.3.1 Inspiration

Peak inspiration in breathing cycle solutions occurs at a phase angle of at t = 2s and t =1s for and , respectively. Sagittal sections of the oro-pharynx, the pharynx, the larynx and the trachea during inspiration for transient breathing cases and constant inspiration (time averaged as well as instantaneous) are depicted in Figure 14. As can be seen, highly turbulent flow occurs in the trachea. The level of the turbulence intensity can be gauged by comparing the flow fields between the instantaneous and time-averaged cases. This is characteristic of the turbulence generated by the effect of the epiglottis and structure of the larynx and very similar to the results of other researchers (Johnstone et al., 2004), (Ball et al., 2008b). The laryngeal jet is clearly visible in the solutions shown in Figure 14, with its strength increasing with increasing flow rate.

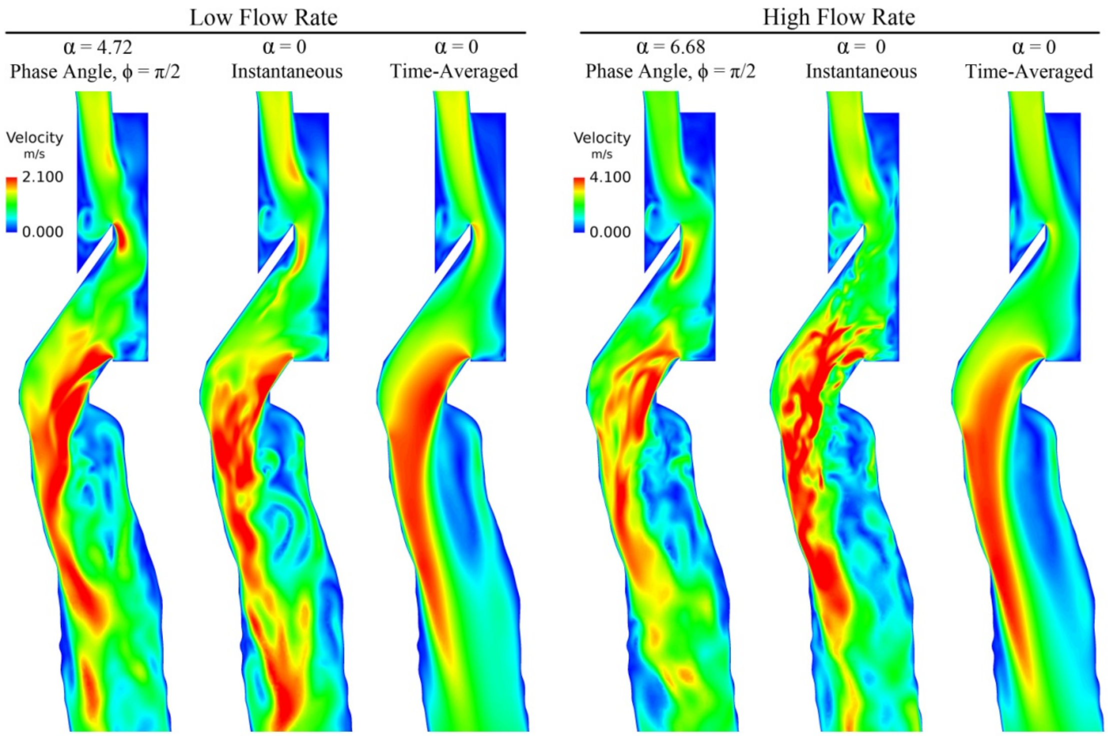


Figure 14. Sagittal cross-section of the ETA including trachea showing velocity magnitude during inspiration

The strength of the flow field between the low and high flow rates can be seen by comparing the time-averaged solutions. The recirculation bubble in the posterior region of the high flow rate is bigger, compared to low flow rate. Hence, for high flow rate greater turbulence level and also more unsteadiness are expected downstream of the trachea. This flow regime with high turbulence intensity has a critical impact on the flow features in the downstream of the lower airway. Iso-surface of Q-criterion for is provided in Figure 15 to have a better insight into this flow phenomenon through the entire airway. In this figure, the presence of highly turbulent flow can be observed through the pharynx, the larynx and the trachea. There is no significant turbulence features in daughter branch or other generations. The feature of turbulence can be seen in the zeroth generation, i.e. the trachea, caused by the complex flow formed by the ETA. These effects can be recognized by comparing the flow pattern at five cross-sections of interest (see Figure 4).

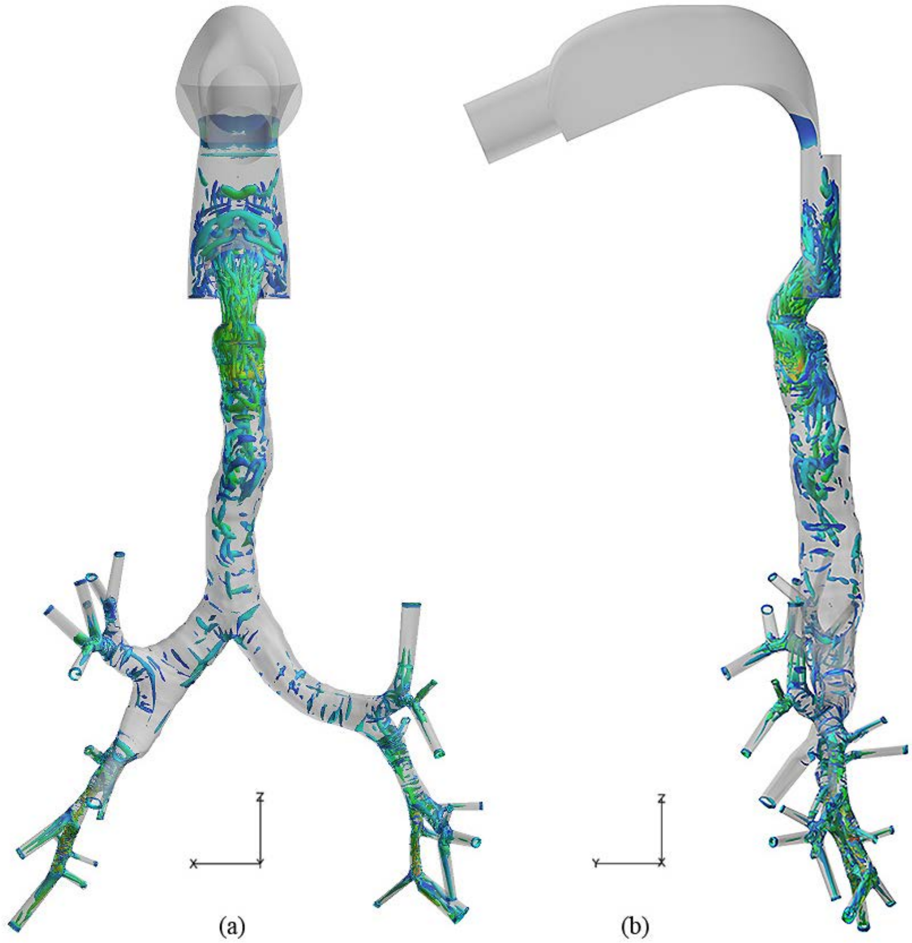


Figure 15. Iso-surface of Q-criterion colored by velocity magnitude for during inspiration. a) Front view b) sagittal view of the entire airway geometry. The geometry is in grey

The effect of the ETA on the flow through the lower airways can be gauged by comparing the solutions obtained for the entire airway geometry with one obtained for the lower airways only in Figure 16. This figure illustrates cross-sectional coronal view of velocity magnitude, limited to 2 m/s, for for the lower airway and the entire geometry. Noticeable differences can be observed between the solutions. A quasi-steady laminar flow occurs in the lower airway, while the entire airway geometry does not show similar flow phenomenon through the trachea and both primary bronchi. Figure 17 provides a better inside into of turbulence features through both airway geometries.

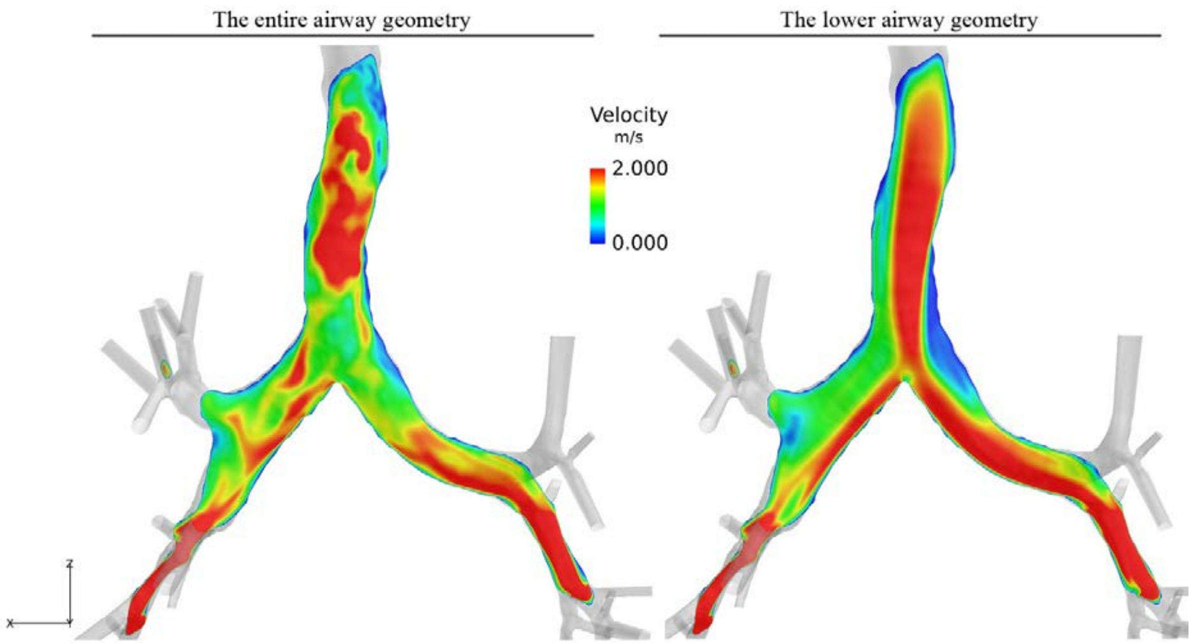


Figure 16. Cross-sectional plane of velocity magnitude is limited to 2 m/s for during inspiration

Figure 17 shows the TKE and turbulence intensity of the entire airway solutions and the lower airway. From the TKE contour in the entire airway, high turbulent flow appeared within the trachea and low level of turbulence decreases within the generations. Conversely, the TKE is almost zero throughout the lower airway geometry.

Turbulence intensity is also zero in the lower airway, whereas turbulence intensity can be spotted in different regions of the entire airway. High turbulence intensity can be found in stagnation points, as can be seen in the first bifurcation and second bifurcation of the right daughter branch. Note that high turbulence intensity is expected in other stagnation points that cannot be seen in this figure. The turbulence intensity is high in the central portion of the trachea downstream of the larynx as well as two sheet-like features near both sides of the wall within the trachea.

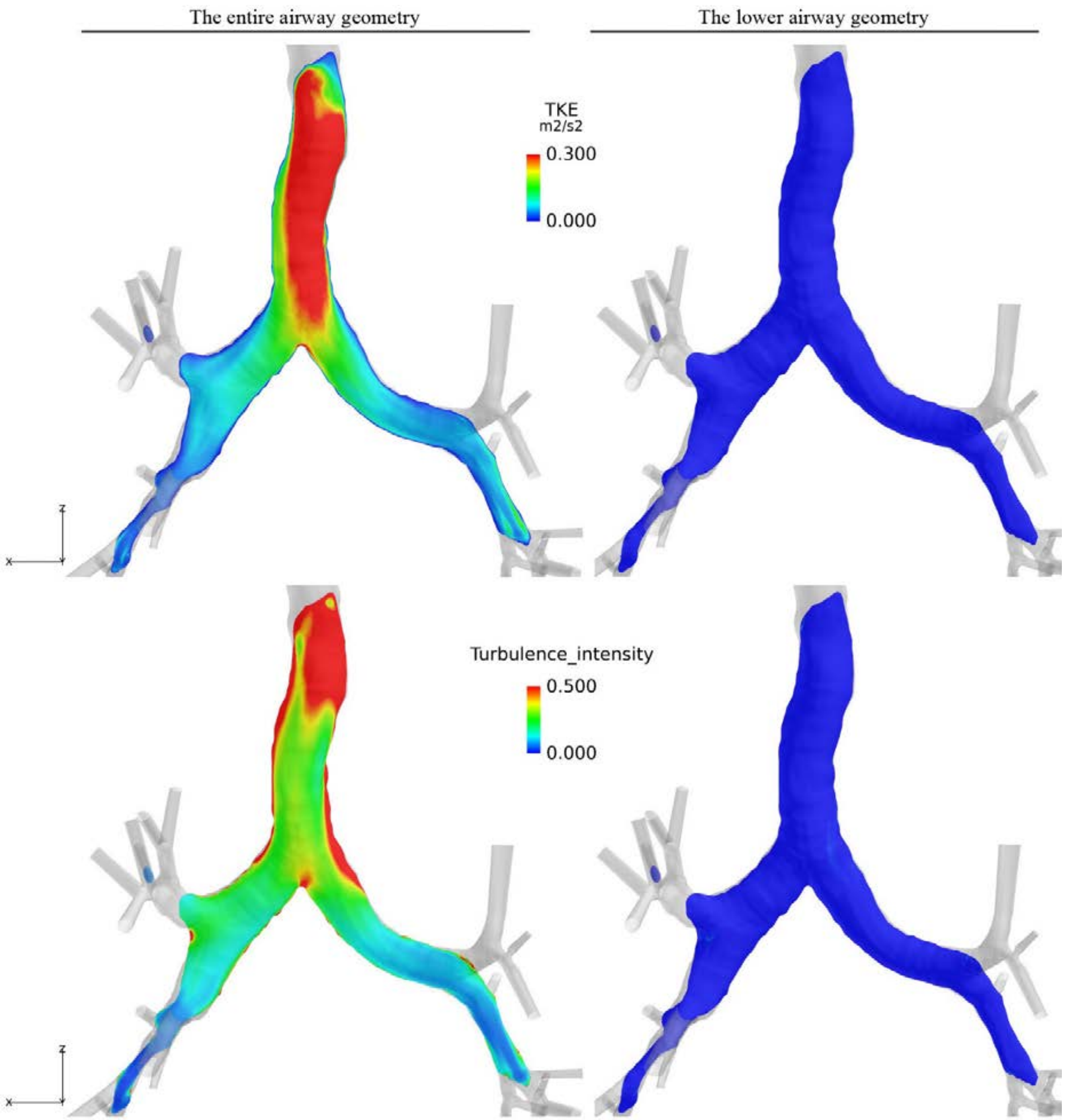


Figure 17. Cross-sectional coronal plane of the first generation of pulmonary airway, illustrating TKE and turbulence intensity for high flow rate during inspiration. The entire airway and the lower airway geometry are on the left and right, respectively. The values limited to 0.3 m^2/s^2 and 0.5, respectively

The flow in the lower airway geometry with practically zero turbulence intensity suggests quasi-steady laminar flow, while the entire airway geometry displays high levels of turbulence through the trachea as well as both primary bronchi. The high-speed laryngeal jet causes this characteristic of the airflow within the trachea and results in high turbulence levels. However, the level of turbulence intensity reduces significantly through the generations. This suggests that the flow through the lower airways is quasi-turbulent and is not significantly affected by the high-speed laryngeal jet.

Secondary flow velocity vectors, colored by velocity magnitude, are shown at various cross-sections (depicted in Figure 13) in Figure 18. The results shown here include that obtained for the entire airway geometry as well as the lower airways geometry. In this figure, only the high flow rate results are shown. This is strictly due to the page number limitation, though the qualitative nature of the comparison is similar between the high and low flow rate cases.

As can be seen from Figure 18, clear differences are visible in the cross-flow velocity vector patterns for the RS, RM and the LI bronchi, while the differences are less pronounced for the other two locations. However, differences in velocity magnitude (the colors in 10) can be seen at these two locations (RI and LS). In the RS, the differences between the two transient breathing solutions are quite clear. The transient breathing entire airway geometry solution shows the presence of two distinct vortices, while the corresponding lower airways solution has three well defined vortices. The differences between the time-averaged solutions are even more pronounced, with the entire airway geometry showing the presence of a single vortex, while two well defined vortices can be seen in the lower airways solution. Another comparison that can be made is between the time-averaged and transient breathing solutions. Comparing these for the entire airway geometry, one can see that there are two vortices for the transient breathing case, while there is a single vortex for the time-averaged case. The presence of the second vortex towards the bottom of the cross-section pushes the other vortex against the edges of the cross-section, effectively squishing it. This also leads to the presence of a higher velocity region down the left side of the cross-section that is absent in the full breathing cycle case. Similar differences can be observed by comparing the time-averaged and transient breathing solutions for the lower airways only. The differences in the secondary flow for the RM are more pronounced compared to the RS bronchus. Similar to the RS, the number of vortices present seems to go up by one when comparing the corresponding time-averaged and transient breathing solutions. The time-averaged lower airways solution has a cloverleaf like pattern, with the fourth vortex being fairly weak. A comparison of the full breathing cycle solutions for the entire airway geometry with the lower airways only case indicates the presence of a vortex towards the top of the cross-section (for the lower case), which is clearly missing from the entire airway geometry.

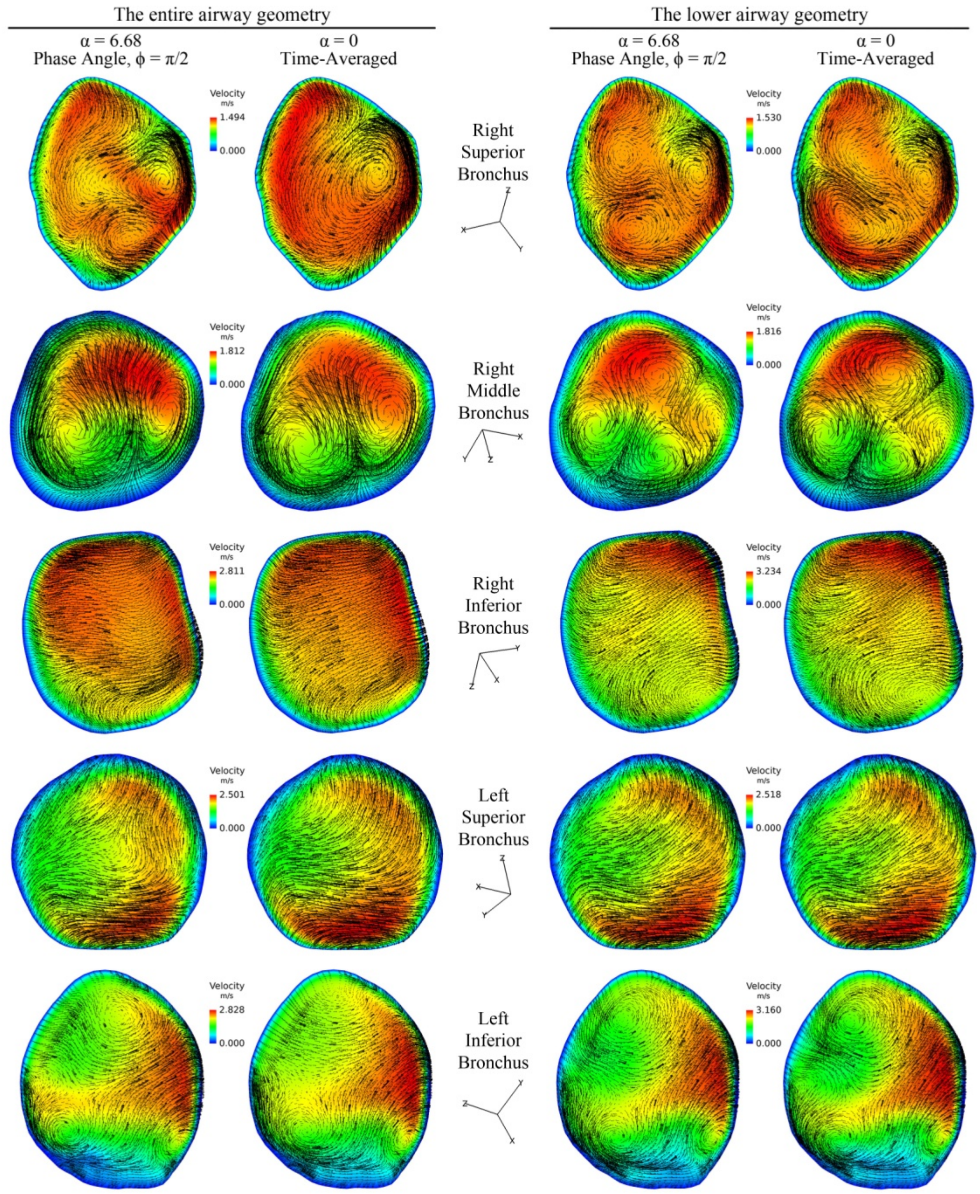


Figure 18. Secondary flows during inspiration for the entire and the lower airway geometry

Only subtle differences are visible in the cross-flow velocity vector patterns between the solutions for the RI, LS, and LI bronchi. Differences are present in the velocity magnitude at all these stations. A possible explanation for these differences could be the distance to these cross-sections from the entrance to the trachea, i.e., the farther you get away from the exit of the ETA, the lesser its effect will be. This is because the low Reynolds number of the flows through the lower airways which tends to damp out most of the turbulent content with increasing residence time.

4.3.2 Expiration

The secondary flow for the expiration case at all cross-sections of lobar bronchus is shown in Figure 19. Again, for the reasons mentioned earlier, only the high flow rate results are shown here. Compared to the inspiration case, only subtle differences are observed between the various solutions. The flow features for all cases are remarkably similar, with the only difference arising in the magnitudes of the velocity between the various cases. This is not surprising given that the flow is now travelling in a direction to opposite to the inspiration case, making the ETA downstream of the lower airways. The effect of the ETA will be felt at best as a slight increase in flow resistance, but the overall flow features are not affected by the presence of the ETA.

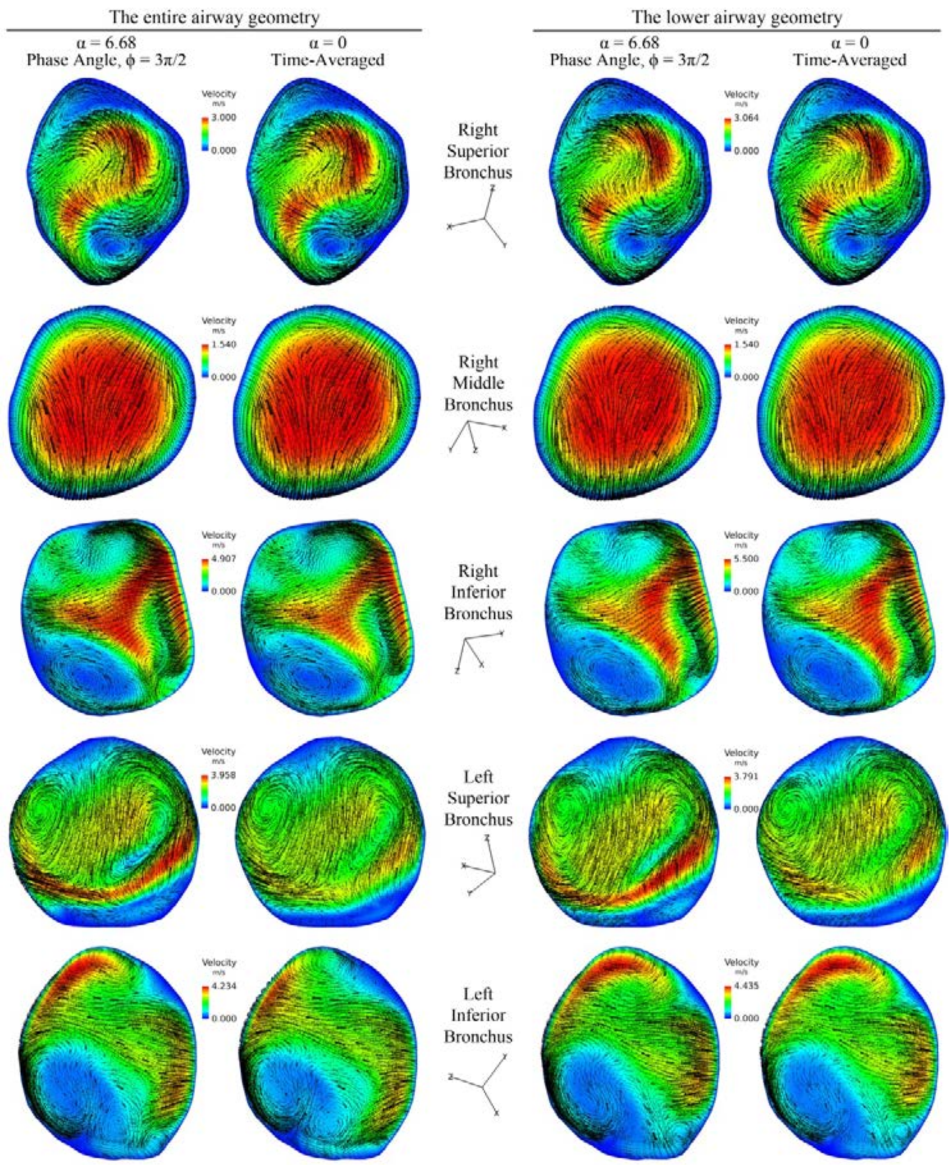


Figure 19. Secondary flows during expiration for entire and the lower airway geometry

The most significant differences between the time-averaged and full breathing cycle solutions for the entire airway geometry are seen in the LI and LS cross-sections, where there are some changes to the cross-flow velocity vector patterns. In the transient breathing solution (LI), an additional vortex appears at the bottom right side that does not exist in time-averaged solution. Furthermore, the velocity magnitude for the time-averaged solution was about 10% lower than the transient breathing one. The maximum velocity (time-averaged) for the RI bronchus was approximately 4.2% lower than the breathing cycle case, while this difference was much more significant in the LS, with 18%. Moreover, in the LS bronchus of the lower airway, prominent differences can be seen in the velocity magnitude of the time-averaged solutions which is approximately 14% less than the transient breathing solution.

The turbulence intensity in the lower airway and the entire airway solutions are provided in Figure 20 to gain insight into the flow regime that exists in the zeroth generation (trachea) and the first generation. The turbulence intensity in both geometries revealed the existence of the turbulent flow during expiration. The level of the turbulence in the lower airway was more pronounced compared to the entire airway solution. This shows the importance of the ETA and its effects on the flow regime within the first bifurcation and the trachea. Higher turbulence intensity appeared in the right primary bronchus of both geometries, with the lower airway having higher values compared to the entire airway geometry.

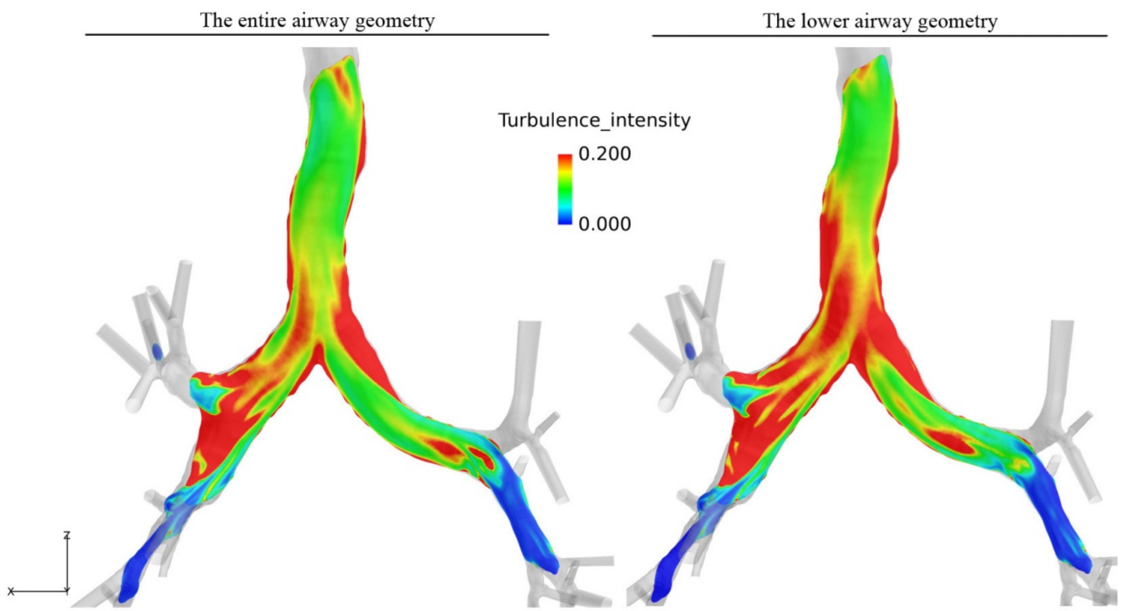


Figure 20. Cross-sectional coronal plane of the first generation of pulmonary airway illustrating turbulence intensity for high flow rate during expiration. The entire airway and the lower airway geometry on the left and right, respectively. The value of turbulence intensity limited to 0.2

It can be seen from Figure 20 that the turbulence intensities are dropping near the trachea. This is consistent with what is seen in Figure 21, which shows a visualization of the turbulent structures present in the ETA, as the turbulent structures are mostly absent in the region of the thorax. However, once the flow passes the glottis, significant turbulent structures appear. This is not surprising given that it is the glottis which causes the laryngeal jet to form during inspiration and the same geometry results in turbulence being generated during expiration.

The changes in the velocity flow field observed in Figure 19 and the turbulence generated in the ETA during expiration could influence particle deposition patterns as one goes through a breathing cycle. Particle inspiration and deposition was not carried out as part of this research; it is however planned as a continuation.

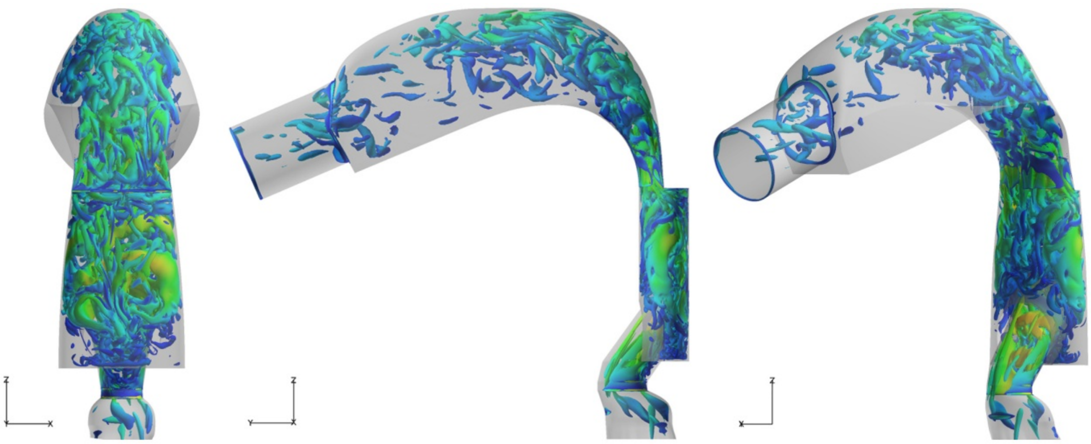


Figure 21. Iso-surface of Q-criterion colored by velocity magnitude for . Behind view, sagittal view and right oblique (45) of the ETA from left to right. The geometry is in grey

5 Conclusions

Computational simulations have been carried out using Tenasi for two different breathing conditions. These computations utilized either an entire geometry or only the lower airways geometry. This allowed for an assessment of the impact of the ETA on the flow through the lower airways.

In the lower airway, irrespective to the presence of the ETA, it was observed that expiratory flows (constant or cyclic breathing) had more fluctuations and unsteadiness compared to inspiratory flows. Conversely, the existence of the ETA increased the levels of turbulence during inspiration. The flow through the ETA is highly unsteady and has significant levels of turbulence in either inspiration or expiration. This manifests itself as differences in velocity distributions at the various lobar planes considered for analysis. These differences could have a significant impact on drug delivery and point to the need for including the ETA geometry in any lower airways simulations.

The impact of constant inspiration/expiration compared to a full breathing cycle was also analyzed by comparing the results of the simulations between peak inspiration/expiration obtained using both the approaches. Significant differences were observed in the simulations pointing to the fact that a constant inspiration/expiration approach might not be sufficient to develop and understanding of these complex flow phenomenon.

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Final Report
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Physics Based Prediction of Stability and Control Characteristics Using Sensitivity-Enhanced Reduced Order Models

Submitted to:

Tennessee Higher Education Commission Center of Excellence in Applied Computational Science and Engineering at the University of Tennessee at Chattanooga

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Physics Based Prediction of Stability and Control Characteristics Using Sensitivity-Enhanced Reduced Order Models

By

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ABSTRACT

Least squares spectral element methods formulate the partial differential equation (PDE) as an optimization problem. One of the advantages of this method is that the boundary conditions can be implemented by adding a penalty equation to the cost function and hence be imposed in a weak sense with little effort. In this study a discontinuous methodology is utilized; that is, each element has its own set of degrees-of-freedom. This formulation possesses a greater sparsity pattern in the Jacobian matrix, and has a smaller bandwidth when compare to the continuous counterpart. However, these attributes come at the expense of an increased number of degrees-of-freedom on a given discretization. In the current work, the conventional discontinuous approach is modified to convert the equations to a matrix free system where there is no need for assembling the global system. The continuity in the formulation between two neighboring elements is imposed in a weak sense with a penalty equation added to the original PDE in each element. This penalty term minimizes the integral of the square root of the difference between the unknown state-vectors on each edge for neighboring elements. The conventional discontinuous approach evaluates this integral at the current time iterate. Using the aforementioned approach, assembly of the system is required and is not matrix free. It is shown in this study that by modifying this equation it is possible to obtain a matrix free system. Additionally each element becomes independent from other elements, and the direct solution for each element possible. The system matrix obtained by this least squares method is symmetric positive definite and can be effectively solved by Cholesky decomposition. This solution procedure is well suited for parallelization using P threads and CUDA. This is due to the fact that there is now no need for any communication, and each element only reads the data from the neighboring elements, while solving for its own unknowns. Another advantage of the matrix free approach is that adaptation is easily implemented by only introducing the new state-vectors into the data structures and updating the neighbor connectivity. The value of the cost function in the formulation may be used to select the elements to be refined. Each tagged element is then divided by h-refinement. This results in a nonconformal mesh. Utilization of a

nonconformal mesh alleviates the need for increasing the resolution in unnecessary locations. To require conformality of the mesh, the extent of refinement and the number of degrees-of freedom are increased. In the current work, quintic quadrilateral elements are used in the simulations, and a C++ vector class is used for updating mesh refinement data structures.

INTRODUCTION

Least squares spectral element method has been used in the past for the solution of the flow problems. This method is based on the conversion of the PDE to an unconstrained optimization problem. This approach has several advantages over the other two methods popularly used in Computational Fluid Dynamic (CFD) analysis, namely, Discontinuous Galerkin and Petrov-Galerkin methods. In this methodology the weighted integral statement is used therefore secondary variables are not present in the discrete equations. In fluid dynamics, the corresponding equations do not contain boundary integrals and thus flux evaluation is not necessary. When applied to nonlinear governing equations of fluid flow, it leads to symmetric positive definite systems. By proper implementation of the boundary conditions of the system, symmetry is preserved. The value of the cost function at each element can be used to detect the elements for refining purposes. In this study P5 spectral element is used for the analysis. This element is shown in Figure 1.

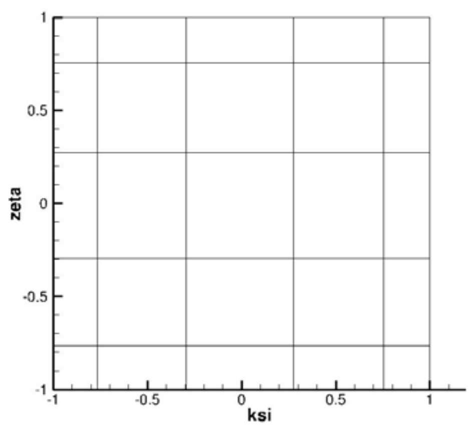


Figure 1. P5 ELEMENT IN COMPUTATIONAL DOMAIN

BRIEF LITERATURE REVIEW

Least squares finite element methods have received sporadic attention in the past decade [1–5]. The least squares finite element method has been previously applied to low Mach number flows by Sheng-Tao et al. [6]. This method for viscous incompressible flow provides sufficient dissipation and has been shown to be inherently stable [7]. Celikkale et. al. [8] show that conservation is recovered by this approach when used along with adaptation. Application of this method to nonconforming grids has been studied by Sert et al. [9]. Akargun et al. [10] has applied h-refinement to capture discontinuities in an unstructured finite element grid. Ponanza et al [7, 11] has utilized the least squares method for the Euler and Navier-Stokes equations in primitive variables. conventional Discontinuous version is also Garrisma et al [12] has demonstrated the use of Newton linearization for the Euler equations using the conservative variables as the primary unknowns. Discontinuous least-squares formulation is first introduced by Aziz et al [13] for a two-domain transmission problem, for which mathematical analysis and numerical results were given by Cao and Gunzburger [14]. Application of the discontinuous least-squares finite element formulation has been also demonstrated by Gerritsma and Proot [15] in the for a first-order one-dimensional model problem, and by Heinrichs [16] for one dimensional singular perturbation model problem.

CONTINUOUS LEAST SQUARES SPECTRAL ELEMENT METHOD

For spectral element methods the band-width of the Jacobian (or Stiffness) matrix becomes very large. Every node shat is in common between two elements will depend on all the nodes from those element. When written in compressed row format this means that ‘ja‘ will include plenty of nodes. This effect varies almost quadratically in two dimensional spaces and cubically in three dimensional space with the order of interpolation polynomial. This dependency actually is beneficial in terms of convergence speed. However, error propagation is also more pronounced due to the same reason. The Least Squares formulation would lead to symmetric Jacobian matrix so only half of this matrix need be stored. And the memory requirement is reduced for this type of formulation. Preconditioned conjugate gradient method can be effectively used to solve the linear system. The penalty function for the method is as follows

$$I = \int R(i)^2 dS, i = 1, \ldots, n \tag{1}$$

where n is the number of equations.

DISCONTINUOUS LEAST SQUARES SPECTRAL ELEMENT METHOD

In discontinuous approach, each element has its own set of degrees of freedom. Now there are no nodes in common. And each node at the edge is only dependent on the edge nodes from the neighboring element and the nodes inside the elements. This effectively reduces the bandwidth of the Jacobian matrix. In the realm of the least squares spectral element method the continuity can weakly be imposed by adding the following penalty function

$$I = \int R(i)^2 dS + \lambda \oint (q - q^*)^2 dl, i = 1, \ldots, n \tag{2}$$

where n is the number of equations and dl stands for the line integral and q* is the unknowns state vector along the edge of the neighboring element. The penalty term basically enforces this integral to be minimized and hence enforces the continuity in a weak sense.

CONVERSION TO MATRIX FREE SYSTEM

The discontinuous least squares spectral element method can easily be converted to matrix free system by modifying the penalty term. Matrix free means the assembling stage of the regular finite element analysis is eliminated and the Jacobian matrix is only formed for each element. Now, instead of evaluating the q* at time step n+1, it is evaluated at time step n, making the system semi-implicit. For higher order system using a preconditioner is inevitable for conventional discontinuous or continuous FEM methods. Conversion to matrix free eliminates the storage of the Jacobian matrix as well as the corresponding preconditioner.

ADAPTIVE H-REFINEMENT AND NONCONFORMAL GRID

Adaptive refinement is crucial in improving the resolution at desired locations in flow in an economic way. For conformal structured grids (i.e. quad elements), local adaptation of one element will lead to adaptation of all the neighboring elements all the way up to the boundaries. This increases the cost of the calculations unnecessarily. On the other hand, if one removes the requirement of conformality on the grid generation process the constraint of the matching points from both sides on the neighboring surfaces will also be eliminated. This in turn, can make the mesh generation process using quad elements less burdensome for practical geometries.

Non-Conformal Mesh Refinement

Except for linear elements, both h-refinement and p-refinements lead to hanging nodes. The modified mesh will include different number of nodes from different sides. Hence form the so-called non-conformal mesh. An example of this is demonstrated in Figure 2. In this study, refinement of the P5 quad elements are accomplished by dividing the element by four new elements. The elements are generated using the midpoints of each edge and the centroid of the element. The one located at the bottom left holds the element number of the element before refinement and the three new elements are labeled in increasing order in counter clockwise rotation. To keep the order of accuracy in curved elements P2 is used to approximate the geometry inside each refined element. P2 requires specification of the central point as well. The coordinates of this point can be easily calculated using the iso-parametric representation of the original element. Having calculated this, one can easily calculate the coordinates using P2 interpolation polynomials. A sample of such a mesh is shown in the Figure 2. This representation of geometry by an order higher than one enables us to generate smooth interior mesh.

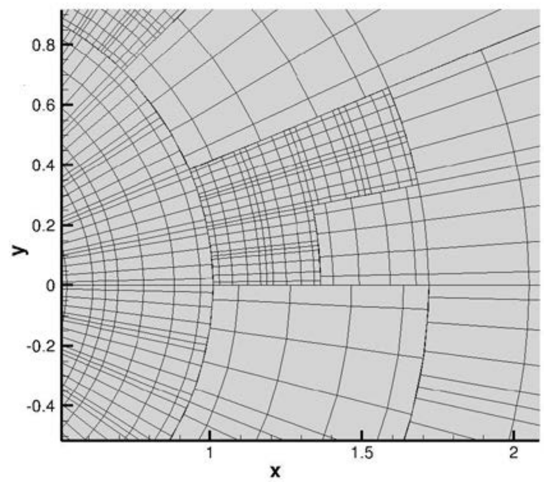


Figure 2. NONCONFORMAL MESH

Virtual Edge Construction

In the Discontinuous Least Squares Spectral Element (DLSSEM) method the continuity across the elements are enforced weakly using a penalty function. At each non-conformal edge, a virtual edge is constructed and the continuity is enforced between this virtual edge and the current edge. There are two types of non-conformal edges. One that has several neighbors. and one that only has one neighbor but shares that edge with some other elements. At first a virtual edge is constructed at each edge and then jump through this face is minimized. To find the location of the Gaus points in neighboring nonconformal edges Newton solver is used. While integrating the continuity penalty parameter the following procedure is implemented to obtain q* . Consider two abutting element 'a' and 'b',

1) Given the Gaus point location for element 'a' in the natural coordinates calculate the location of the Gaus point in the physical space, i.e. Xp and Yp

$$\begin{aligned} X_p^a &= \sum X_i^a \Phi_i \\ Y_p^a &= \sum Y_i^a \Phi_i \end{aligned} \tag{3}$$

2) Identify which neighbor holds that points (as now each element can have multiple neighbors)

3) Using the coordinates of the neighbor form the isoparametric representation of the neighboring edge, i.e.,

$$\begin{aligned} X_p^a &= \sum X_i^b \Phi_i(\zeta, \eta) \\ Y_p^a &= \sum X_i^b \Phi_i(\zeta, \eta) \end{aligned} \tag{4}$$

4) Solve the above nonlinear equation using a Newton metlζ,η for
5) Interpolate the unknown vector at that location for the element
6) Assume this value as q*
7) Loop over for the next Gaus point

GOVERNING EQUATIONS

In this study, the Euler and Laminar Navier-Stokes equations are numerically solved using the matrix free DLSSEM. Conversion to laminar flow follows redeclaration of the PDE in first order form. This will eliminate the need for computing the second order derivatives at the expense of introducing more independent variables.

Euler Equations In Conservative Form In Two Dimensions

Conservative formulation is a necessity to capture the location of the discontinuities (i.e. shocks) in the flow.

$$\frac{\partial Q}{\partial t} + \frac{\partial F}{\partial x} + \frac{\partial G}{\partial y} = 0 \qquad (5)$$

Performing chain rule, one will get the linearized form as follows:

$$\frac{\partial Q}{\partial t} + A\frac{\partial Q}{\partial x} + B\frac{\partial Q}{\partial y} = 0 \qquad (6)$$

At this point one can assume that the coefficients appearing at the nonlinear terms are known from the previous iteration. This assumption will lead to the Picard linearization. In other words, a nonlinear convective term at iteration (n+1) is approximated in the following manner:

$$Q^{n+1}\frac{\partial Q^{n+1}}{\partial x} = Q^{n}\frac{\partial Q^{n+1}}{\partial x} \qquad (7)$$

The alternative way is to use Newton linearization. This approach is illustrated as follows. Consider the conservative variable Q^{n+1} at iteration n+1, $Q^{n+1} = Q^n + \Delta Q$.

Consider $Q^{n+1}\frac{\partial Q^{n+1}}{\partial x}$ to be a sample convective term,

inserting the above mentioned relation into this nonlinear equation will give:

$$(Q^n + \Delta Q)\frac{\partial (Q^n + \Delta Q)}{\partial x} = Q^n\frac{\partial Q^n}{\partial x} + Q^n\frac{\partial \Delta Q}{\partial x} + \Delta Q\frac{\partial Q^n}{\partial x} + \Delta Q\frac{\partial \Delta Q}{\partial x} \qquad (8)$$

By neglecting the higher order terms it follows, $\Delta Q\frac{\partial \Delta Q}{\partial x}$

$$(Q^n+\Delta Q)\frac{\partial(Q^n+\Delta Q)}{\partial x}\simeq Q^n\frac{\partial Q^n}{\partial x}+\Delta Q\frac{\partial Q^n}{\partial x}+Q^n\frac{\partial \Delta Q}{\partial x} \quad (9)$$

Inserting back the relation for ΔQ yields;

$$Q^n\frac{\partial Q^n}{\partial x}+\Delta Q\frac{\partial Q^n}{\partial x}+Q^n\frac{\partial(Q^{n+1}-Q^n)}{\partial x} \quad (10)$$

by rearranging, and plugging back $\Delta Q+Q^n=Q^{n+1}$ in

$$Q^{n+1}\frac{\partial Q^{n+1}}{\partial x}=Q^{n+1}\frac{\partial Q^n}{\partial x}+Q^n\frac{\partial Q^{n+1}}{\partial x}-Q^n\frac{\partial Q^n}{\partial x} \quad (11)$$

The Euler equations are linearized using this method. For more detail see [12]. The only disadvantage of using this type of linearization is the generation of rational polynomials, for which the number of Gauss points required for exact integration cannot be decided beforehand. Albeit it might suffice to evaluate these terms approximately for most of the problems. Here, the conservative form of the equations are used. However, the primitive variables used as primary variables in the solution procedure. Using the transformation between the primitive and conservative variables i.e. Q = Mq the following is achieved,

$$M\frac{\partial q}{\partial t}+L_1\frac{\partial q}{\partial x}+L_2\frac{\partial q}{\partial y}=0 \quad (12)$$

Using the Newton linearization on the nonlinear terms in $L_1\frac{\partial q}{\partial x}+L_2\frac{\partial q}{\partial y}$ the equation takes the following form;

$$M\frac{\partial q}{\partial t}+L_0q+L_1\frac{\partial q}{\partial x}+L_2\frac{\partial q}{\partial y}=f \quad (13)$$

At the convergence L0q = f the equation reduces to the original form. This fact can be used as a verification of the derivations of L0 and f . These coefficients are presented in appendix A. The point is the equations are not multiplied by M-1, and hence the conservative property is preserved at each time step. The change in the conservative variables are calculated at each iteration. The other advantage is that using this technique, neither of the coefficients contain any rational polynomials, now the number of nodes can be specified for exact integration of each term as each term is a polynomial itself. The third advantage noted in the verification procedure is the method used here provides better up-winding and dissipation, in comparison to the direct linearization of the conservative Euler equations with conservative variables as primary variables used in [12]. This is noticed in the grid convergence study in the method of manufactured solution. In addition, it also reduces the burden of chain rule differentiation when viscous terms are involved.

Laminar Navier-Stokes Equations in Conservative Form

The continuous version for the Least Squares Spectral Element (LSSEM) method is given in [17]. The nondimeniosnal form of the laminar Navier-Stokes equations in first order form are given as,

$$
\begin{aligned}
R_1 &= \frac{\partial \rho}{\partial t} + \frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y} \\
R_2 &= \frac{\partial(\rho u)}{\partial t} + \frac{\partial(\rho u^2 + p)}{\partial x} + \frac{\partial(\rho u v)}{\partial y} - \frac{\partial \tau_{xx}}{\partial x} - \frac{\partial \tau_{xy}}{\partial y} \\
R_3 &= \frac{\partial(\rho v)}{\partial t} + \frac{\partial(\rho u v)}{\partial x} + \frac{\partial(\rho v^2 + p)}{\partial y} - \frac{\partial \tau_{yx}}{\partial x} - \frac{\partial \tau_{yy}}{\partial y} \\
R_4 &= \frac{\partial(\rho E)}{\partial t} + \frac{\partial((\rho E + p)u)}{\partial x} + \frac{\partial((\rho E + p)v)}{\partial y} \\
&\quad - \frac{\partial(\tau_{xx} u + v\tau_{xy} - q_x)}{\partial x} - \frac{\partial(\tau_{xy} u + v\tau_{yy} - q_y)}{\partial y} \\
R_5 &= \tau_{xx} - \frac{2}{3}\mu \frac{M_\infty}{Re_\infty}\left(2\frac{\partial u}{\partial x} - \frac{\partial v}{\partial y}\right) \\
R_6 &= \tau_{xy} - \mu \frac{M_\infty}{Re_\infty}\left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right) \\
R_7 &= \tau_{yy} - \frac{2}{3}\mu \frac{M_\infty}{Re_\infty}\left(2\frac{\partial v}{\partial y} - \frac{\partial u}{\partial x}\right) \\
R_8 &= q_x + k\frac{M_\infty}{Re_\infty Pr_\infty Ec_\infty}\left(-\frac{p}{\rho^2 R}\frac{\partial \rho}{\partial x} + \frac{1}{\rho R}\frac{\partial p}{\partial x}\right) \\
R_9 &= q_y + k\frac{M_\infty}{Re_\infty Pr_\infty Ec_\infty}\left(-\frac{p}{\rho^2 R}\frac{\partial \rho}{\partial y} + \frac{1}{\rho R}\frac{\partial p}{\partial y}\right)
\end{aligned}
\tag{14}
$$

where the temperature gradients in the heat fluxes have been written in terms of pressure and density using the equation of state.

The free stream Reynolds number, Prandtl number and speed of sound are defined as Re_∞, Pr_∞, and c_∞, respectively.

Grid Generation For Higher Order Spectral Elements

Commercial grid generation softwares generate P1 elements. It is more convenient to try to generate higher order meshes from the mesh generated by these softwares. The most conventional way is to linearly interpolate the points for the higher order elements,at the locations required by the tensor product of the GLL (Gaus-Legendre-Lobatto) points in the nodal spectral element method.

Geometry Snapping For Higher Order Elements

To be able to maintain the order of accuracy, the geometry under study should be modeled at least with the same order of accuracy. This requires the snapping of the Legendre points on the elements at the boundaries to the solid boundaries based on the arc-length. This is done by using a parametric curve distribution for NACA0012 airfoil in this study. In order to maintain the quality of the mesh, linear elasticity equations are used to deform the mesh according to the locations of the points obtained from the geometry [18]. These equations are formulated at the same order of the flow solver to take advantage of the already developed code [19]. Galerkin FEM [20] is used for the analysis. One should notice that, this procedure introduces some error for elements as it moves the interior nodes without regard to their new Gaus-Legendre-Lobatto (GLL) points. This issue is more noticeable in bigger elements. For those types of situations, it is better to regenerate the interior points inside the element using Trans-Finite Interpolation (TFI) [21] method to remove the error generated during the process.

PARALLELIZATION USING MULTIPLE THREADS

This methodology leads to a pleasingly parallel algorithm which is very suitable for multi-thread programming. The shared data between the threads is read-only, hence the iteration takes place without any need for synchronization or blocking communication. It is worth noting that this method is designed for shared memory paradigm therefore running this in serial is extremely inefficient and slow. Very appealing for CUDA due to the power of launching thousands of threads. However, one needs to have access to the hardware. A simpler version can be easily implemented using C++ OPENMP library. The latter is used for parallelization in this study.

VERIFICATION WITH METHOD OF MANUFACTURED SOLUTION (MMS) ON NONCONFORMAL GRID

This method is widely used to verifying the numerical solution procedure. In this procedure one assumes a predefined field for the independent variables. These variables certainly do not satisfy the original equations. Therefore plugging these into the original PDE will lead to a source term. Adding this source term to the equations, one will try to recover the known results by solving the new PDE. The solution is presented in Figure 3 for comparison.

NUMERICAL RESULTS

Several standard test cases are used to demonstrate the ability of this method. The analysis includes flow over a smooth geometry i.e. a cylinder at subsonic flow. The second test case is NACA0012 in subsonic and transonic flows conditions. This geometry is included to account for the effect of the geometric and solution singularities on the method. The next test case is supersonic flow over a five degree ramp and the final case is low mach number laminar flow around a circular cylinder. Three level adaptation is applied to the cases unless stated otherwise.

Subsonic Inviscid Flow Around a Cylinder

The flow around a cylinder is simulated at M=0.3 and AOA=0.0. The results for this case is presented in Figure 5. The initial mesh and the final mesh consist of 24 and 228 elements, respectively. The solutions for these two cases are presented in Figure 6 for comparison. In order to preserve symmetry, symmetric adaptation is enforced. Since the path the optimization takes till the convergence is not necessarily symmetric, without enforcing this condition, the solver will perform adaptation in an asymmetric way which is not desirable for the case under study here.

Subsonic Inviscid Flow over NACA0012 Airfoil

The flow condition for this case is set as M=0.5 and AOA=2.0 degrees. The final result at the end of adaptation is presented in Figure 7. The initial mesh and the final adapted mesh are presented in Figure 8. The initial mesh is the same for both subsonic and transonic cases and consists of 266 elements. The number of elements for this case at the end of adaptation is 554.

Transonic Inviscid Flow over NACA0012 Airfoil

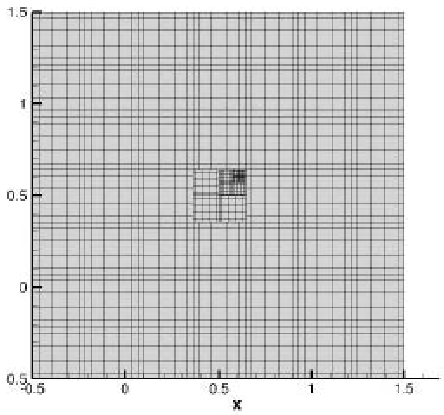
The flow condition for this case is set as M=0.8 and AOA=0.0 degrees. The solution to this problem is presented in Figure 9 and the final mesh is presented in Figure 10. The number of elements for initial and final meshes are 266 and 2078, respectively.

Supersonic Inviscid Flow over Ramp

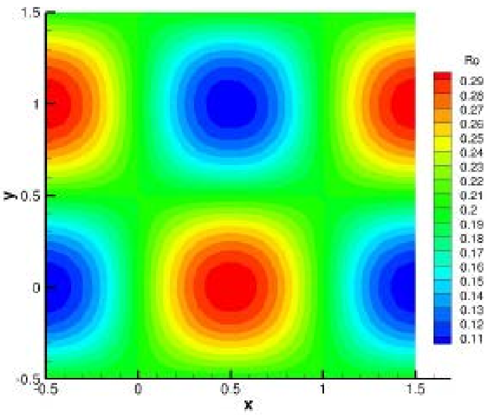
Flow over a 5:0 degree ramp for M=2.0 and AOA=0.0 is presented. The grid is adapted for four levels. The corresponding solution fields are presented in Figure 11. The improvement of the adaptation over the initial solution is demonstrated in Figure 12. Four level adaptation is used for this case. Initial mesh has 30 elements. This numbers increases to 786 at the end of adaptation.

Laminar Viscous Flow over Cylinder

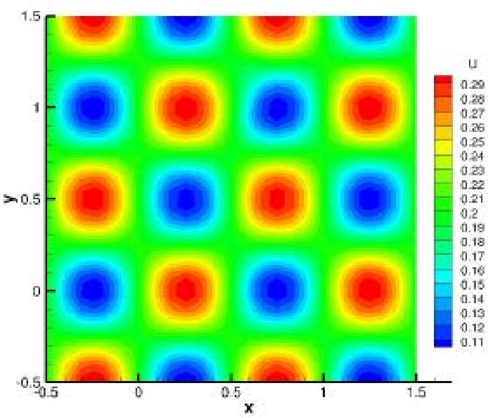
Flow over unit diameter circular cylinder at M=0.2 and AOA=0.0 and Re=20, is presented. Once again, three level adaptation is carried out. The initial and final meshes have 178 and 374 elements and are shown in Figure 13. This flow is indeed low speed and may be considered as incompressible. The solution is presented as a validation with incompressible flow. The variation in density is very small as expected for this flow condition.



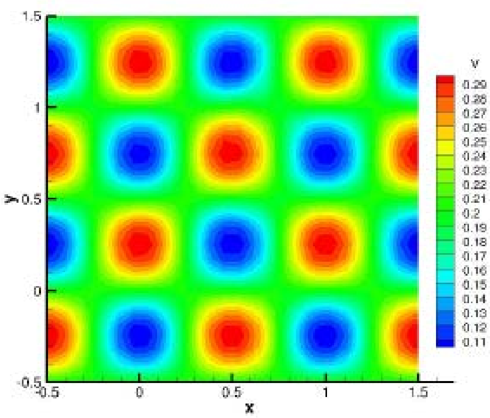
(a) MMS Grid



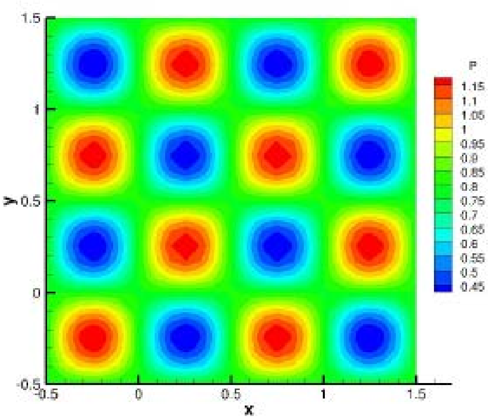
(b) MMS Density



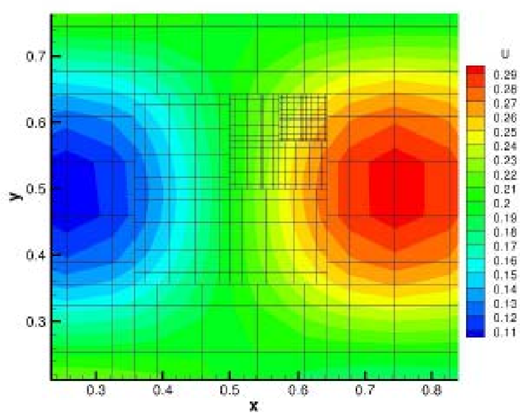
(c) MMS U component of Velocity Vector



(d) MMS V component of Velocity Vector

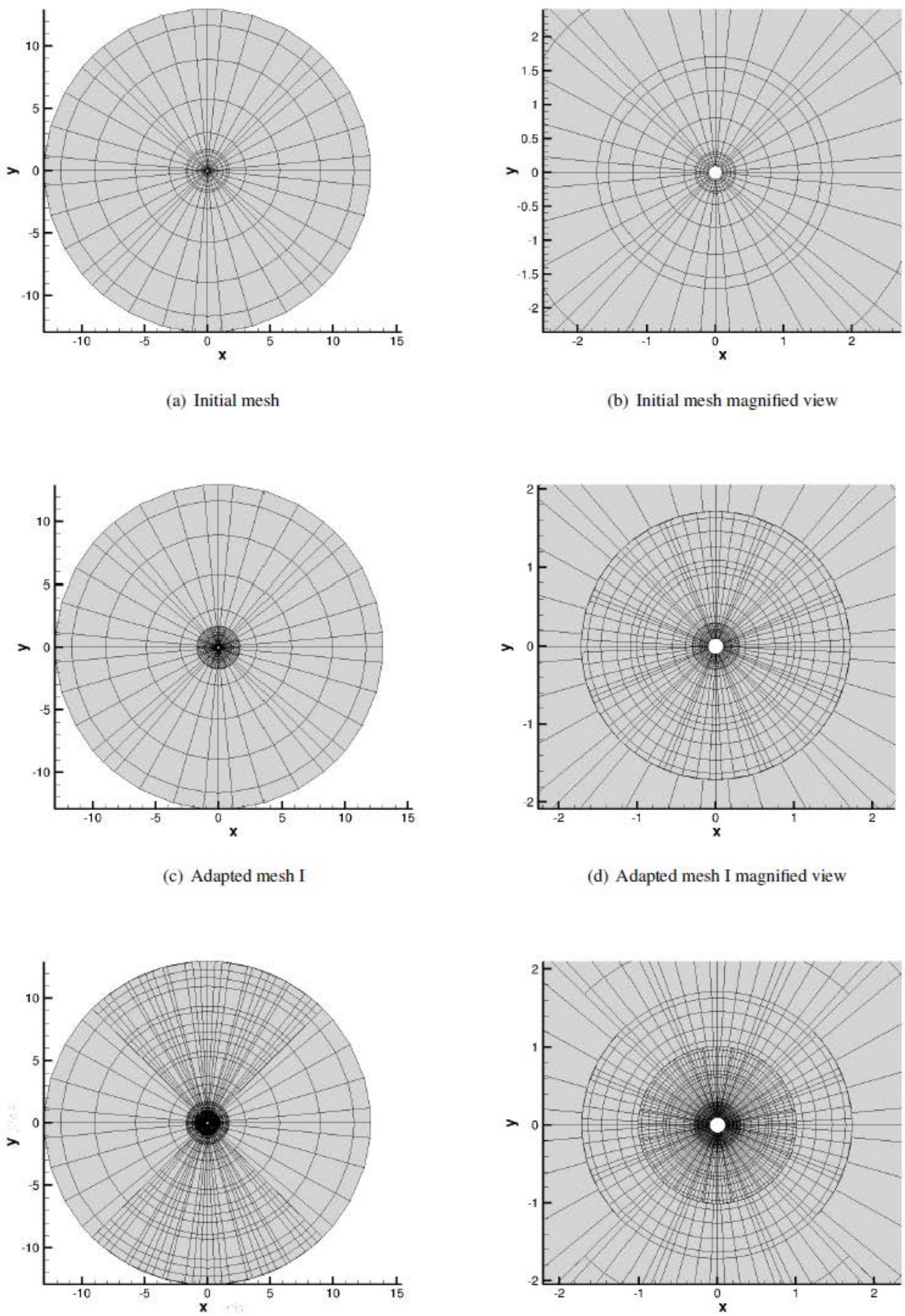


(e) MMS Pressure



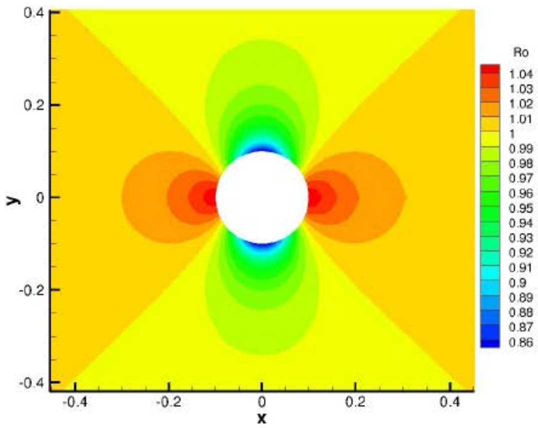
(f) Magnified view

Figure 3. VERIFICATION OF THE NUMERICAL METHOD USING THE METHOD OF MANUFACTURED SOLUTIONS

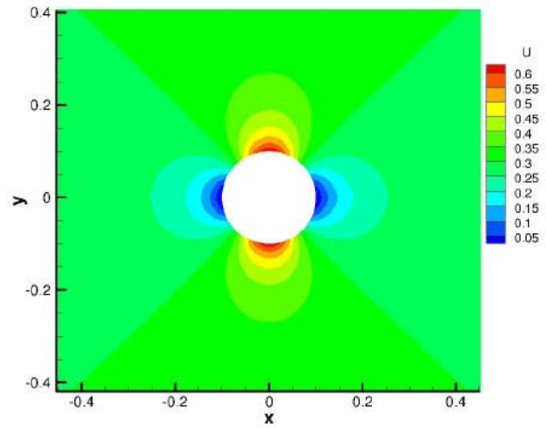


(a) Initial mesh
(b) Initial mesh magnified view
(c) Adapted mesh I
(d) Adapted mesh I magnified view
(e) Adapted mesh II
(f) Adapted mesh II magnified view

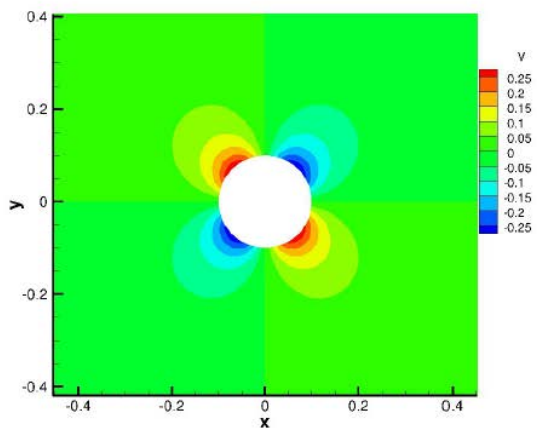
Figure 4. GRID FOR THREE LEVEL ADAPTATION FOR FLWO AROUND A CYLINDER



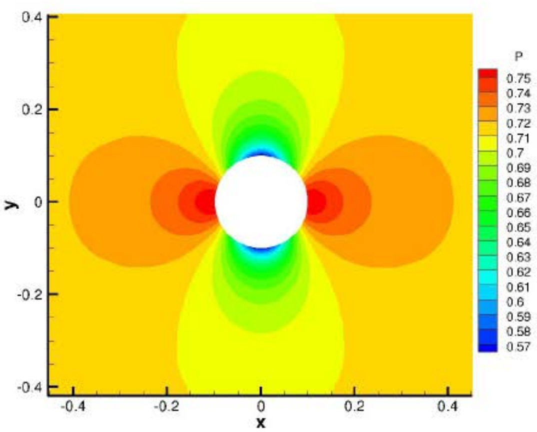
(a) Density



(b) U Component of Velocity



(c) P Component of Velocity



(d) Pressure

Figure 5. FLOW AROUND A UNIT DIAMETER CYLINDER M=0.3 AND AOA=0.0

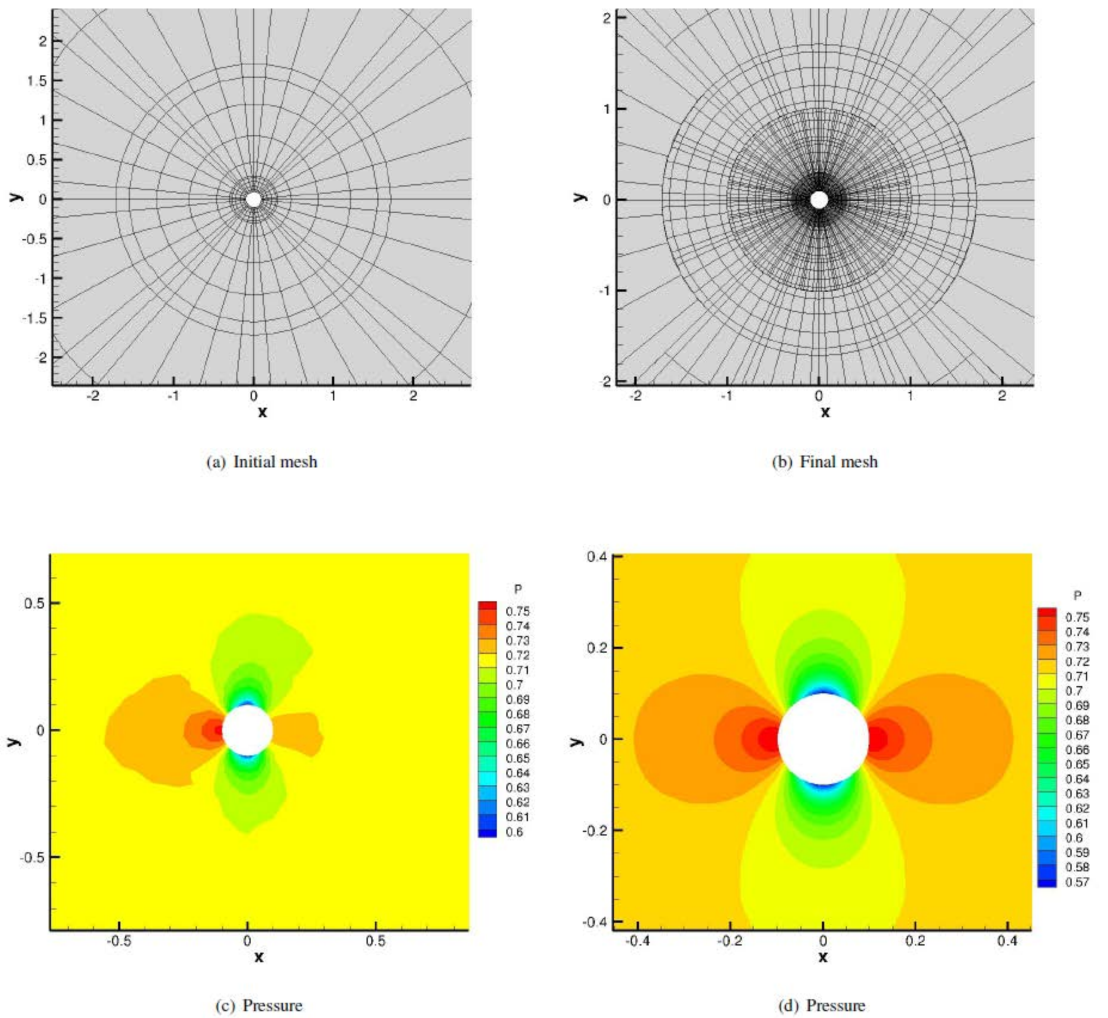
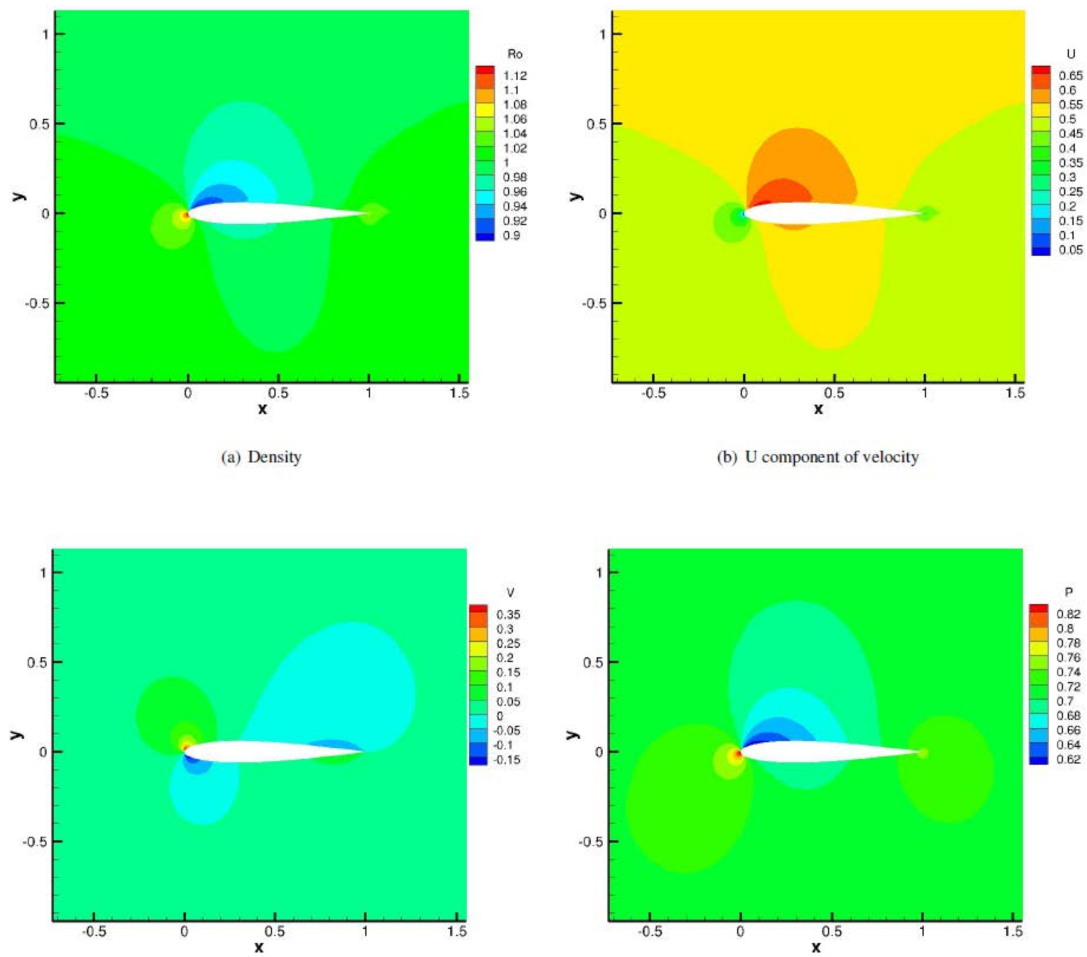


Figure 6. FLOW AROUND A UNIT DIAMETER CYLINDER M=0.3 AND AOA=0.0



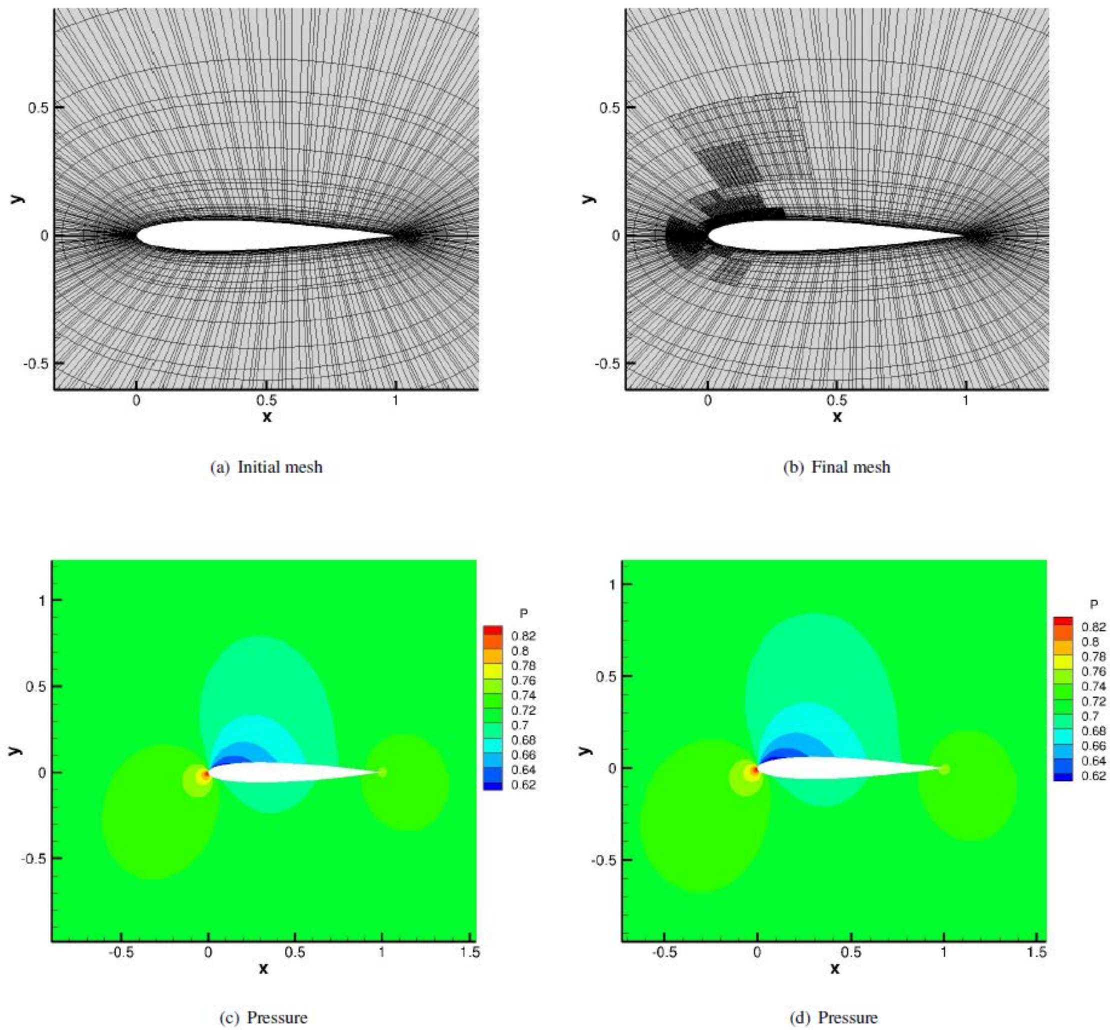
(a) Density

(b) U component of velocity

(c) V component of velocity

(d) Pressure

Figure 7. FLOW AROUND A NACA0012 AIRFOIL FOR M=0.5 AND AOA=2.0



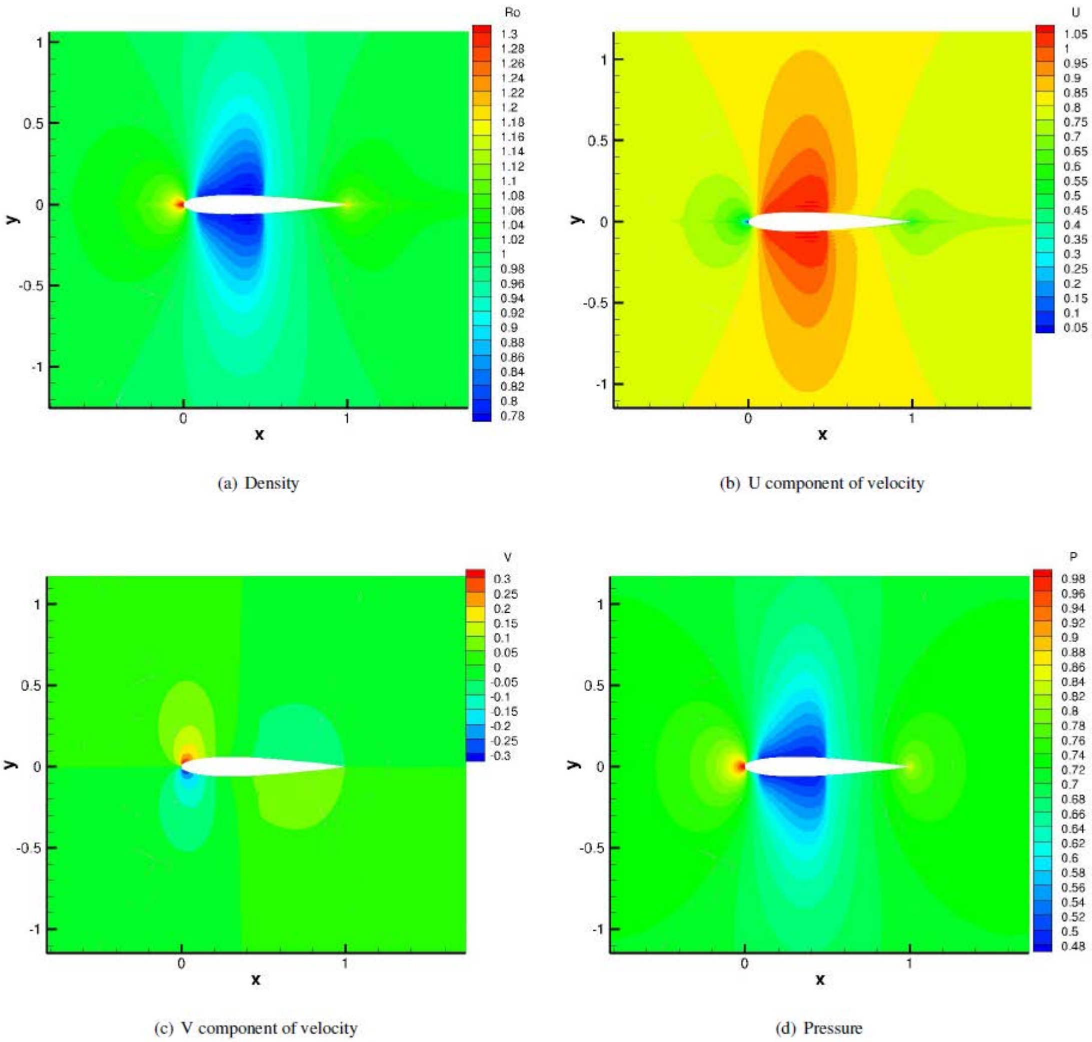
(a) Initial mesh

(b) Final mesh

(c) Pressure

(d) Pressure

Figure 8. FLOW AROUND A NACA0012 AIRFOIL FOR M=0.5 AND AOA=2.0



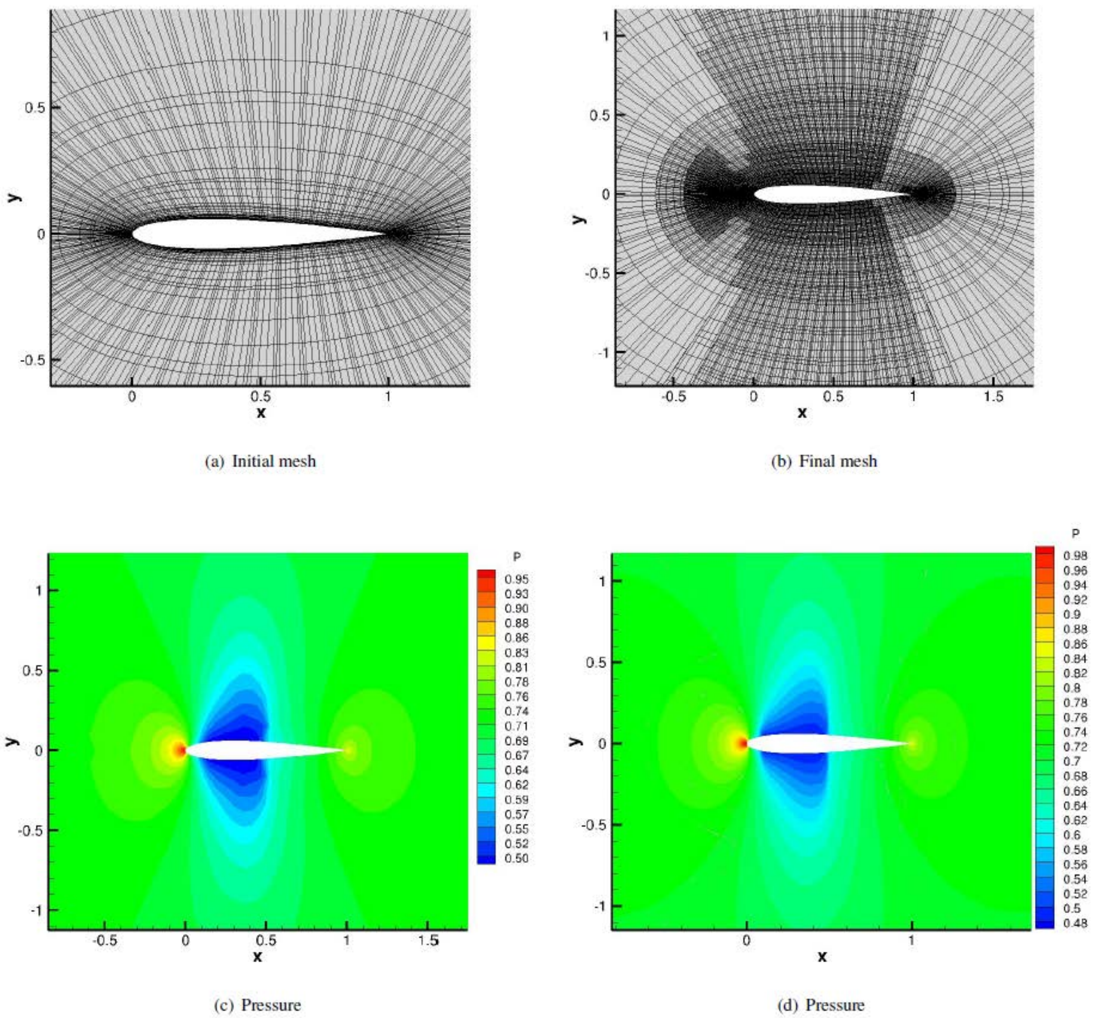
(a) Density

(b) U component of velocity

(c) V component of velocity

(d) Pressure

Figure 9. FLOW AROUND A NACA0012 AIRFOIL FOR M=0.8 AND AOA=0.0



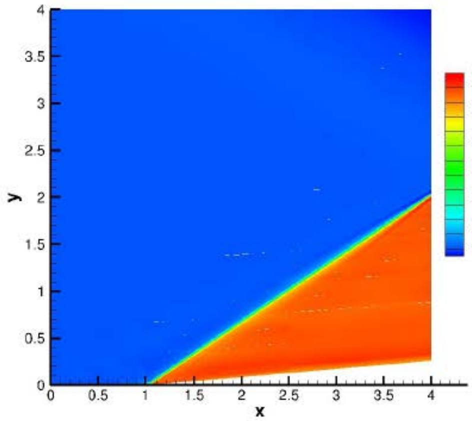
(a) Initial mesh

(b) Final mesh

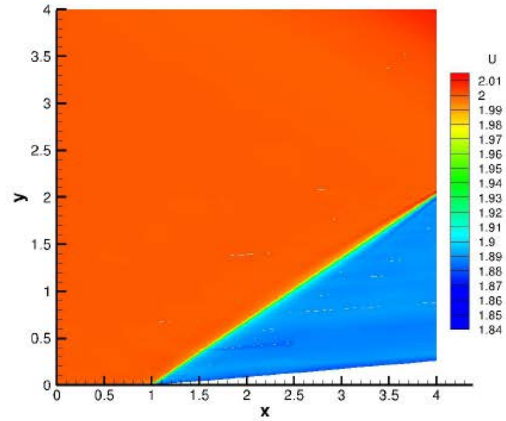
(c) Pressure

(d) Pressure

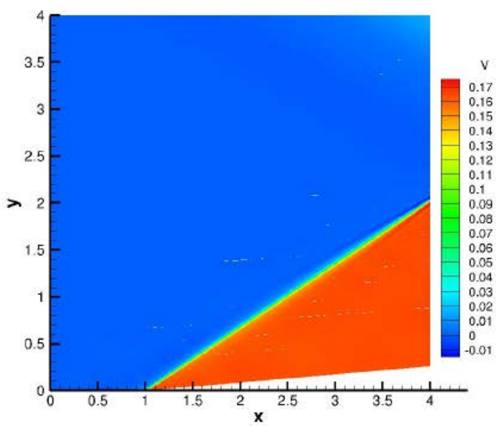
Figure 10. FLOW AROUND A NACA0012 AIRFOIL FOR M=0.8 AND AOA=0.0



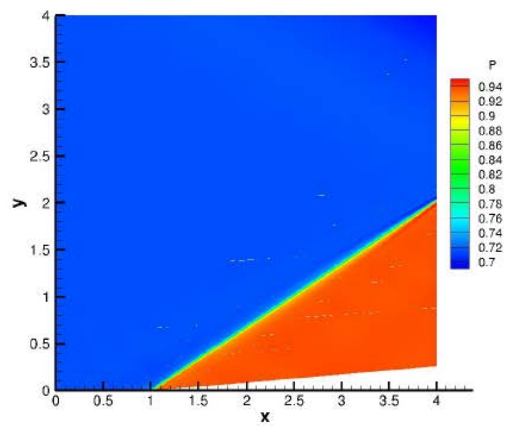
(a) Density



(b) U Component of Velocity

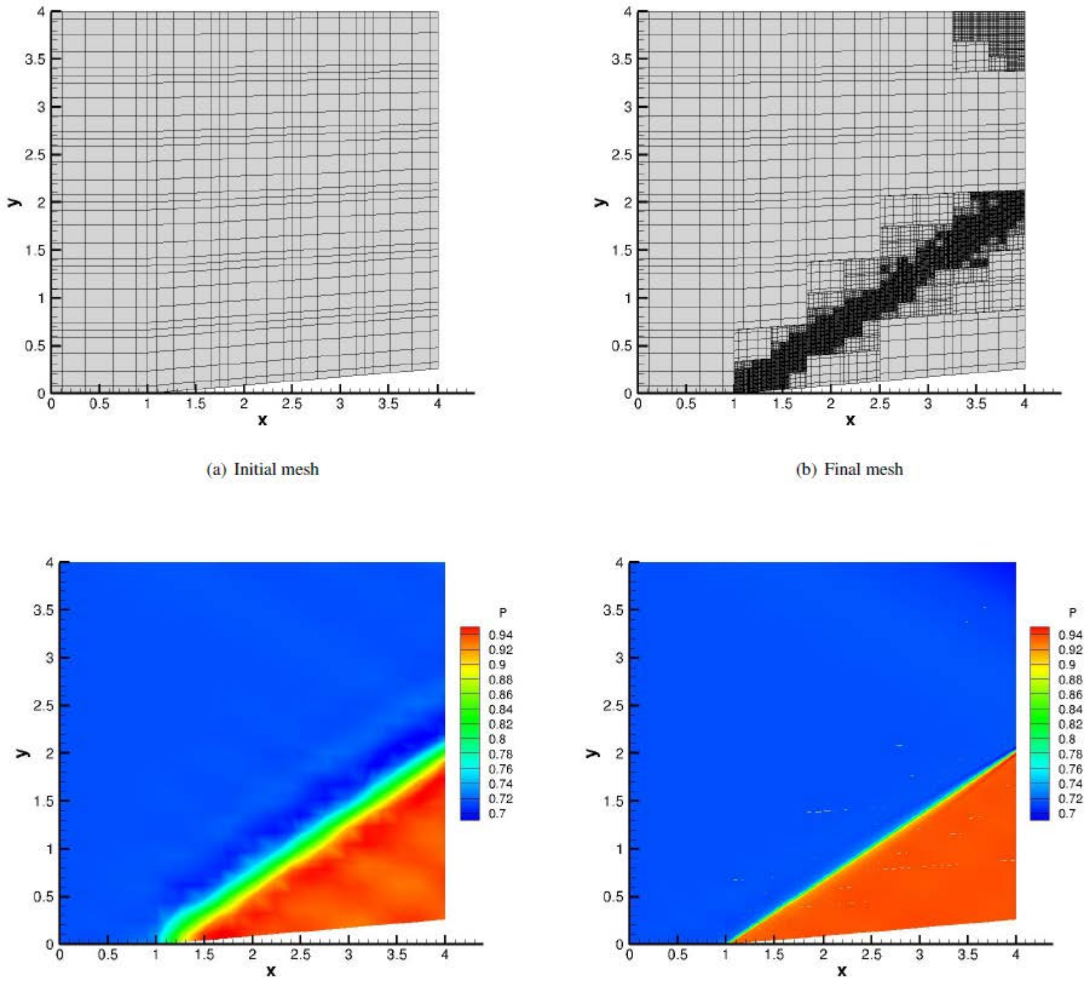


(c) V Component of Velocity



(d) Pressure

Figure 11. FLOW OVER RAMP M=2.0 AND AOA=0.0



(a) Initial mesh

(b) Final mesh

(c) Pressure

(d) Pressure

Figure 12. FLOW OVER RAMP M=2.0 AND AOA=0.0

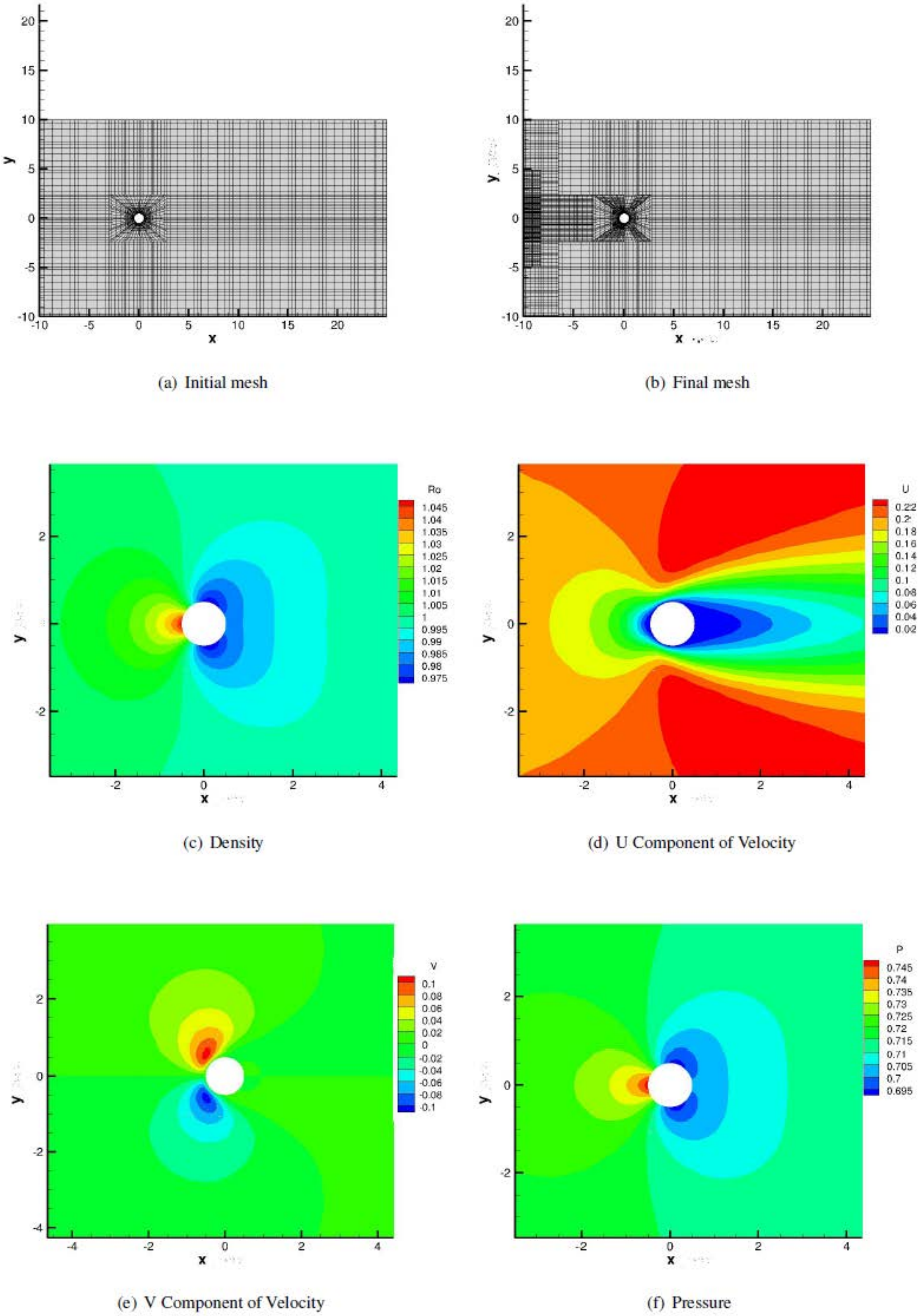


Figure 13. FLOW AROUND A UNIT DIAMETER CYLINDER M=0.2 AND AOA=0.0 Re=20

VALIDATION

1) The validation here is presented for the supersonic case. Given the deflection angel of the ramp and the free stream Mach number, one can easily calculate the shock angle using theoretical aerodynamics [22]. For the problem under consideration here, this angle is found to be 34.3 degrees. The “y” location of the shock at the outlet boundary is approximately 2.04, therefore the shock angle calculated here numerically is 34.1 degrees, which shows that they are in good agreement.

2) The second case is the flow at M=0.5 and AOA=1.25, the results are compared to finite volume results of Vassberg and Jameson [23]. Cp for both cases are compared in Figure 14.

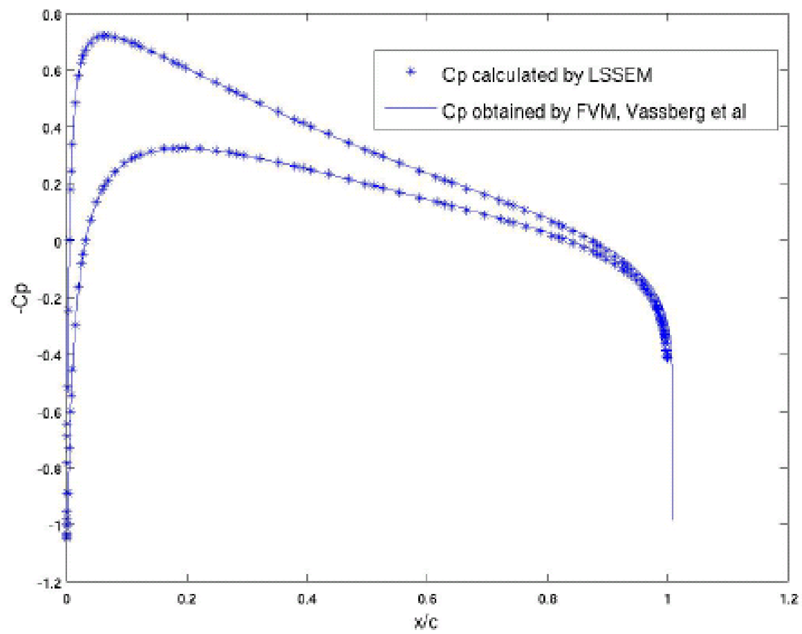


Figure 14. COMPARIOSN OF PRESSURE COEFFICIENT

CONCLUSIONS

A pleasingly parallel Matrix Free Least Squares Spectral Element method with h-refinement is developed for steady-state Euler and Laminar Navier-Stokes equations. In this approach, unlike the regular contentious methods, continuity between the elements are enforced in a week sense. A simple modification of this penalty function enables us to obtain a pleasingly parallel algorithm suitable for any shared memory programming paradigm such as CUDA or P threads. It also makes the adaptation procedure extremely easy to implement. The method is not very efficient for transonic flows as due to the presence of the discontinuity and using the strong form of the equations. However, that property is inherited form the least squares formulation and is present even in continuous solution. The method is not numerically economical for solving transonic problems due to excessive dissipation, this is a well known characteristic of the least squares finite element methods and is not a result of the solution algorithm presented here. Another important point to mention is that, adaptation is dependent on the design of the detector function and the final adapted mesh is not unique. The unsteady adaptation using this methodology will be subject matter of another study and will be reported by the authors.

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Appendix A: Coefficients from Newton Linearization of Euler Equations

$L_0(0,0) = \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}$
$L_0(0,1) = \frac{\partial \rho}{\partial x}$
$L_0(0,2) = \frac{\partial \rho}{\partial y}$
$L_0(0,3) = 0.0$
$L_0(1,0) = 2\frac{\partial u}{\partial x}u + \frac{\partial v}{\partial y}u + \frac{\partial u}{\partial y}v$
$L_0(1,1) = 2\frac{\partial u}{\partial x}\rho + \frac{\partial v}{\partial y}\rho + 2\frac{\partial \rho}{\partial x}u + \frac{\partial \rho}{\partial y}v$
$L_0(1,2) = \frac{\partial u}{\partial y}\rho + \frac{\partial \rho}{\partial y}u$
$L_0(1,3) = 0.0$
$L_0(2,0) = 2\frac{\partial v}{\partial y}v + \frac{\partial u}{\partial x}v + \frac{\partial v}{\partial x}u$
$L_0(2,1) = \frac{\partial v}{\partial x}\rho + \frac{\partial \rho}{\partial x}v$
$L_0(2,2) = 2\frac{\partial v}{\partial y}\rho + \frac{\partial u}{\partial x}\rho + 2\frac{\partial \rho}{\partial y}v + \frac{\partial \rho}{\partial x}u$
$L_0(2,3) = 0.0$
$L_0(3,0) = \frac{1}{2}(3u^2+v^2)\frac{\partial u}{\partial x} + \frac{1}{2}\frac{\partial v}{\partial y}(u^2+3v^2) + uv(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x})$
$L_0(3,1) = \frac{\partial \rho}{\partial x}(3u^2 + v^2) + \rho(\frac{\partial v}{\partial y}u + \frac{\partial u}{\partial y}v) + \rho(3\frac{\partial u}{\partial x}u + \frac{\partial v}{\partial x}v) +$
$\frac{\gamma}{\gamma-1}\frac{\partial p}{\partial x} + \frac{\partial \rho}{\partial y}uv$
$L_0(3,2) = \frac{\partial \rho}{\partial y}(u^2 + 3v^2) + \rho(\frac{\partial v}{\partial x}u + \frac{\partial u}{\partial x}v) + \rho(3\frac{\partial v}{\partial y}v + \frac{\partial u}{\partial y}u) +$
$\frac{\gamma}{\gamma-1}\frac{\partial p}{\partial y} + \frac{\partial \rho}{\partial x}uv$
$L_0(3,3) = \frac{\gamma}{\gamma-1}(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y})$
$f_0 = \frac{\partial u}{\partial x}\rho + \frac{\partial v}{\partial y}u + \frac{\partial \rho}{\partial y}v$
$f_1 = 2\frac{\partial \rho}{\partial x}u^2 + 4\frac{\partial u}{\partial x}\rho u + 2\frac{\partial v}{\partial y}\rho u + 2\frac{\partial u}{\partial y}\rho v + 2\frac{\partial \rho}{\partial y}uv$
$f_2 = 2\frac{\partial \rho}{\partial y}v^2 + 2\frac{\partial v}{\partial x}\rho u + 4\frac{\partial v}{\partial y}\rho v + 2\frac{\partial v}{\partial v}\rho u + 2\frac{\partial \rho}{\partial x}uv$
$f_3 = \frac{3}{2}\frac{\partial \rho}{\partial x}u(u^2+v^2) + \frac{3}{2}\frac{\partial \rho}{\partial y}v(u^2+v^2) + \frac{\gamma}{\gamma-1}(\frac{\partial p}{\partial x}u + \frac{\partial p}{\partial y}v) +$
$\frac{3}{2}\frac{\partial u}{\partial x}\rho(3u^2+v^2) + \frac{3}{2}\frac{\partial v}{\partial y}\rho(3v^2+u^2) +$
$\frac{\gamma}{\gamma-1}p(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}) + 3\rho uv(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x});$

THEC

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CUMULATIVE FINAL REPORT

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PROJECT OVERVIEW

Lead PI	*List personnel as you would like for them to appear in a formal report – e.g., Dr. John Smith / John Smith, PhD, etc.* Nesli Alp, Ph.D., PE
Co-PI(s)	Endong Wang, Ph.D., CPC
Other Personnel	*Identify by type – senior personnel, technicians, graduate students, undergraduate students*
Project Title	Energy Performance of Residential Buildings Using Simple-Normalization Based Two-Stage Data Envelopment Analysis
Date Submitted	
Award Start - End Date	07/01/2015-06/30/2017
Non-Technical Summary – 500 words or less	*Please provide a non-technical summary of your project that addresses the major objectives, accomplishments, and outcomes of your project. Discuss impacts of the project in terms of scholarly contributions to the field, scholarly outputs, student and community impacts, etc. Address how your project advanced or supported the mission of the SimCenter.* Residential energy performance assessment, i.e. how efficiently a house is consuming energy compared to its peers, plays an essential role in judging whether the house structure needs to be retrofitted. Many aspects regarding design, materials, climate and occupancy can influence the performance of a house. Thus, the identification of key components that result in energy waste is of critical importance to ensure an effective retrofitting investment without wasting money. However, existing performance evaluation tools on the market often fail to provide the desired information to make valid decisions for effective investments in retrofitting projects. One major challenge associated with current models is that they cannot differentiate the energy effects of various energy factors. Our project proposed a new method based on data envelopment analysis (DEA) to reliably isolate the impacts of energy factors by classifying them into climate factors, management factors and scaling factors. We applied the developed model to a case region in Iowa. The results showed that the model can be useful in accurately providing in-depth information to decision-makers for building retrofitting. The developed method can be used by owners, property managers, policy makers to draw more reliable decisions in building energy efficiency area. The proposed project expands the research coverage of SimCenter to residential energy efficiency.

ACCOMPLISHMENTS & OUTCOMES

Project Overview
Provide a scientific / technical overview of your research project – hypothesis or scientific aims, methodologies and activities, outcomes, etc. Identifying detailed meta-factors of building energy performance is of importance for creating effective residential building energy-retrofitting strategies. Compared to other benchmarking methods offering aggregated general performance indices, nonparametric DEA (data envelopment analysis) is capable of discriminating scale factors from management factors to generate more detailed indicators to better guide retrofitting practices. An improved two-stage DEA energy benchmarking method includes first-stage meta DEA which integrates the common degree day metrics for neutralizing noise energy effects of exogenous climatic variables and censored Tobit regression for advanced efficiency analysis. A simple-normalization of degree-day based two-stage DEA approach is developed for benchmarking building energy performance to assist in achieving informed decisions for effective residential retrofitting.

List of Objectives / Aims / Major Milestones Proposed	Cumulative Outcomes / Accomplishments

Add rows as needed.

Challenges & Strategies Used to Address / Overcome:
Discuss any challenges or barriers that you encountered, particularly if you were impeded from achieving the objectives and milestones approved in your proposal. Building energy data are rare. No physical lab space or equipment to do onsite experiments.

What didn't work? What did you disprove or learn from the parts that didn't meet your initial concept at the proposal?
Describe any areas where you did not meet goals; negative results are important too and should be explained and documented. Mostly, what did you learn besides what you achieved whether it met your expectations at the outset of this effort? More fundamental research may need to be done to understand residential energy performance.

IMPACT & OUTCOMES

Impact on the career(s) of the PI, the co-PIs, and key collaborators	This project helped the PI and Co-PI to strengthen their research in this area by patriating in academic seminar, attending conferences, and publishing articles.
Students Impacted	*Please list students including name, brief description of how they were impacted, what degree sought or when graduated, and any other relevant details.* Emil Jada – MS Engineering Management Mawazo Fortunas – MS Engineering: Civil They both helped with the THEC ITQ Workshop for teachers and TBAEE grant

<table>
<tr><td>Community and Broader Impacts</td><td>Consider and discuss the technical and actual or potential societal impacts of your research project.
The results of this project have already drawn attentions from academia with discussions and citations.

The results will definitely benefit industry professionals for their retrofitting activities when adopted.
Science and Math teachers from Hamilton county and other neighboring counties attended the hands-on Energy workshop at UTC in June 2017

We are currently helping an underrepresented community by fixing and renovating their houses in a small scale to save energy</td></tr>
<tr><td>Work products reduced to practice; provide a bibliographical entry where appropriate</td><td>Please include software, papers, presentations, posters, and creative works. Indicate Refereed Journal, Refereed Conference, Non-refereed Conference for each publication listed. For journal publications, indicate the impact factors where appropriate.
1. Wang E, Alp N, Shi J, Wang C, Zhang X, Chen H (2017). Multi-criteria building energy performance benchmarking through variable clustering based compromise TOPSIS with objective entropy weighting. <u>Energy</u> 125: 197-210. Impact Factor: 4.520
2. Wang E, Shen Z, Alp N, Barry N (2015). Benchmarking energy performance of residential buildings using two-stage multifactor data envelopment analysis with degree-day based simple-normalization approach. Energy Conversion and Management, 106: 530-542. Impact Factor: 5.589
3. Wang E, et al. (2017). Climate Effects in Data Envelopment Analysis for Residential Energy Performance Benchmarking---An Empirical Case Validation. 2018 Conference Proceedings (ASCE), New Orleans, Louisiana, USA, April 2-5, 2018 (Under review).</td></tr>
<tr><td>New inventions reduced to practice and when they will be formally disclosed;</td><td>Please consider and include new software products that are subject to copyright but also methods and systems are potentially patentable. If you filed invention disclosures, patent or copyright applications during the period of performance, please indicate so here as well. If you wish to open source a software prototype data set, please state so; we will follow up with you with a disclosure process and guidance on how to proceed effectively for UTC and our research program, including required steps prior to doing so, and how properly to credit ownership to the UT system.</td></tr>
<tr><td>Outreach & Collaboration</td><td>Please list any visitors, workshops, or other collaborative events did you hold? Indicate the location (on campus, etc.).

THEC ITQ Workshop for High School Science and Math Teachers in Tennessee – June 19-23, 2017</td></tr>
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EXTERNAL FUNDING

<table>
<tr>
<td>Proposal Submissions</td>
<td>
Please list all sponsored program proposals submitted during the reporting period related to this or previous CEACSE awards.

Endong:
1. NSF PROPOSAL PREPARATION INITIATIVE--- Integrated Efficient Environmental Sustainability Modeling of Built Environments
2. Alfred P. Sloan Foundation---Building Energy Efficiency Analysis
3. CRISP--- 3D Printing Technology for Sustainable Construction
4. ORAU travel grant
5. TDOT research ideas
6. NSF-China---Open-Block Oriented Designing Methods and Strategy

Nesli:
1. NSF ITEST PROPOSAL - EXploring Clean Energy through hands-on Learning (EXCEL)
Requested Budget: $1,170,501
Submitted: August 2016
PI: Nesli Alp
Co-PI: Endong Wang
Not funded

2. THEC Improving Teachers Quality (ITQ) PROPOSAL - EXploring Clean Energy through hands-on Learning (EXCEL)
Submitted: September 2016
Requested Budget: $73,911
PI: Nesli Alp
Funded
3. Tennessee Board of Architecture and Engineering Examiners (TBAEE) Special Grant
Submitted: October 2016
Requested Budget: $20,000
PI: Nesli Alp
Funded
4. NSF ITEST PROPOSAL - Real-world Additive Manufacturing Projects for Underrepresented Participants (RAMP UP)
Submitted: August 2017
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<tr><td></td><td>Requested Budget: $1,005,619
PI: Nesli Alp
Waiting for the result
5. NSF Advanced Technological Education (ATE) PROPOSAL - 2+2 MET: Developing an Industry-Responsive Mechatronics AAS to BAS Pipeline for Engineering Technicians
Requested Budget: $586,997
PI: Nesli Alp
Waiting for the result</td></tr>
<tr><td>Contracts / Awards Received</td><td>List any awards or agreements received / executed related to this or previous CEACSE awards. Include sponsor name, sponsor program name (if applicable), project title, and award amount. If it is a non-funding agreement, identify by type (e.g., Data Use Agreement, Non Disclosure Agreement, Material Transfer Agreement, etc.).
1. THEC Improving Teachers Quality (ITQ) PROPOSAL - <u>EX</u>ploring <u>C</u>lean <u>E</u>nergy through hands-on <u>L</u>earning (EXCEL)
Submitted: September 2016
Requested Budget: $73,911
PI: Nesli Alp
Funded
2. Tennessee Board of Architecture and Engineering Examiners (TBAEE) Special Grant
Submitted: October 2016
Requested Budget: $20,000
PI: Nesli Alp
Funded</td></tr>
<tr><td>Sponsored Program Capacity Building Activities</td><td>List all capacity-building activities in which you have engaged during the award period. Examples may include meeting with a sponsor program officer, attending an NSF/NIH/other sponsor regional workshop, participating in GWSW activities, attending on-campus workshops, etc.

Activities Endong attended:
1. NIH workshop (On campus)
2. Thermal sensing workshop (Georgia)

Activities Nesli attended:
1. Additive Manufacturing Workshop (Knoxville, TN)
2. Robotics Park Visit (Huntsville, AL)</td></tr>
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WHAT'S NEXT FOR THIS RESEARCH?

How will you follow up your CEACSE grant with work in the next 1,2, … 5 years?	We will continue to work on this research area and collaborate with other faculty.
What other related research will you pursue (and with whom) in light of the support you've received from CEACSE?	
Tell us anything else we should know about this work not described above.	
What barriers (if any) do you face to reach these next goals?	

FINANCIAL ACCOUNTING

Financial Report:	**Total Award Amount:**	$91,000.00
	Cumulative Expenditures:	$81,104.54
	Remaining Award Amount:	$2,895.46

Please attach the following:

- *Final ledger report showing the final accounting for your award.*
- *Line item budget spreadsheet comparing your original, approved budget to how funds were actually expended.*
- *Updated budget narrative describing how funds were expended and how expense contributed to the achievement of project goals, objectives, and milestones.*

Supplemental Award Request	*Have you or do you anticipate applying for a supplemental award for any portion of the remaining balance? If so, please include the amount requested (or planned).*	$