THEC ACADEMIC PROGRAM REVIEW

Computational Engineering Graduate Program

Self Study for the Ph.D. in Computational Engineering Program

Academic Years 2004-2009

December 2009
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EXECUTIVE SUMMARY

The purpose of the Computational Engineering Ph.D. program is to prepare graduates to develop and apply advanced computational modeling, simulation, and design software for a broad range of real-world engineering analysis and product design problems. Graduates are also prepared to contribute their expertise in an environment of interdisciplinary teamwork.

The program offers a unique educational environment in which students participate in interdisciplinary team research at the UTC SimCenter, with opportunities for significant interaction with multiple researchers. The SimCenter solves diverse but computationally related computational engineering problems using interdisciplinary teamwork, supported by an internally developed and shared software base (Tenasi) and by cost-effective dedicated computer resources.

The program has become fully established during its first five years, growing to an enrollment of 20 Ph.D. students and awarding 10 Ph.D. degrees. The faculty also operates the Computational Engineering Concentration of the M.S. in Engineering degree program, with a current enrollment of 15 M.S. students and 11 M.S. degrees awarded.

Significant development of the program has occurred during the initial five-year period. An extensive orientation and advisement process has been developed for new students in this interdisciplinary program. Six new courses have been developed and added to the original five courses, and two special courses have been taught by invited instructors. A process for faculty monitoring and assessment of student participation in team research has been established. Other improvements to the educational environment include a new one-hour course to provide basic orientation and instruction in computer skills needed early in the program, and introductory projects for new students giving practical experience in scientific programming for computational engineering applications.

The program believes it is having good success in meeting its educational goals and outcome objectives.
PART I – HISTORY AND BACKGROUND

A. History of the University of Tennessee at Chattanooga

The University of Tennessee at Chattanooga, a metropolitan university since 1969, has historical roots in two private institutions: The University of Chattanooga (UC) and a junior college, Chattanooga City College (CCC). UC was founded by an agency of the Methodist Episcopal Church in 1886, consolidated as Grant University with Tennessee Wesleyan University in 1889, and renamed The University of Chattanooga in 1907. CCC, with a predominantly African-American student population, was created in 1964 as a non-sectarian successor to Zion College, which had been established as a junior college in 1949. The University of Chattanooga and Chattanooga City College merged in 1969 with The University of Tennessee System, one of the oldest land-grant institutions in the nation, to form The University of Tennessee at Chattanooga (UTC).

UTC earned the Carnegie Community Engagement classification in both Curricular Engagement and Outreach and Partnerships areas in 2008. The University’s wide diversity of degree programs has attracted a current enrollment of more than 9,800 students representing all Tennessee counties, all states, and many foreign countries.

B. History of the SimCenter and Computational Engineering Program

The University of Tennessee SimCenter at Chattanooga and the UTC Graduate School of Computational Engineering were both established in late 2002. This was the result of a shared vision to form an engineering research center in Chattanooga, to begin UTC’s first Ph.D. program, and to initiate external engagement activities that would ultimately support technology innovation and economic development in Chattanooga. These initiatives were enabled in part by large grants from the Lupton Foundation and UC Foundation and by contributions of time and resources from many other people and institutions. The SimCenter occupied its current 31,000 sq. ft. research and education facility in November 2003.

The Computational Engineering program received approval in April 2003 to offer a Concentration in Computational Engineering within the existing M.S. in Engineering at UTC. It received approval from the Tennessee Higher Education Commission (THEC) in January 2004 to offer the Ph.D. in Computational Engineering. UTC received approval from the Southern Association of Colleges and Schools (SACS) in April 2004 for a substantive change in status to a Ph.D. granting institution. The Computational Engineering Ph.D. program officially commenced operation in the fall semester of 2004. The Computational Engineering program has grown rapidly and currently has 20 Ph.D. and 15 M.S. students enrolled. It has awarded 11 M.S. and 10 Ph.D. degrees since its inception in 2004. The SimCenter has also supported 19 undergraduate research associates during this period.

Mission - The broad mission of the SimCenter is to establish next-generation technologies and innovative interdisciplinary education in computational modeling, simulation and design, with consequent leadership in related national critical technology areas. Its goals include supporting industry through external interactions and partnerships that help focus its research on important problems, providing access to analytical services and computational tools, and by producing graduates who are prepared for interdisciplinary team research.
C. SimCenter Expansion of Research, Education, and Metropolitan Engagement

In November 2007, the SimCenter was designated by the University of Tennessee System as the SimCenter: National Center for Computational Engineering. This began a SimCenter effort to expand the scope of its research, education, and metropolitan engagement programs to encompass transition of its modeling and simulation technology to a commercial-ready form. This transformative expansion is enabled by approximately $17 million in contributions over five years from a group of Chattanooga supporters including the Benwood, Lyndhurst, and UC Foundations, as well as the UT System, Maclellan and Tucker Foundations, Community Foundation of Greater Chattanooga, and anonymous donors. The first year’s funding increment was received in September 2009.

The SimCenter will continue and grow its integrated research and education program within a Computational Engineering Academy comprised of all of its faculty, staff, and students. Special projects for technology transition will be sponsored by a SimCenter-affiliated nonprofit Applied Resource Center that will seek to commercialize this technology for businesses and industry in the form of analytical services and software licenses. The Applied Resource Center will enable the SimCenter to serve as a resource for economic development that will attract, expand and nurture high-technology businesses in Chattanooga and Tennessee. The expansion will also enable the SimCenter to increase its impact on national critical technologies affecting defense, sustainable energy, environment, transportation, and health.

Websites
SimCenter: http://www.utc.edu/Research/SimCenter/
Computational Engineering: http://www.utc.edu/Academic/ComputationalEngineering/

PART II – STUDENT EXPERIENCE

A. Admission Requirements

Applicants must meet the following admission requirements:

Graduate School Requirements

- Hold a baccalaureate or master’s degree from a regionally accredited college university or foreign equivalent;
- Baccalaureate degree holders must have a minimum grade point average (GPA) of 2.7 on a 4.0 scale, or a 3.0 in the senior year; Master’s degree holders must have a cumulative GPA of 3.0 on a 4.0 scale for graduate level coursework;
- Have a minimum 550 (paper-based), or 213 (computer-based), or 79 (internet-based) TOEFL score, or 6.0 on the IELTS for international students, or qualify for a Graduate School exemption from this requirement;
- Submit letter of recommendation from senior manager or professor;
- Submit official transcripts from each institution previously attended;
- Complete the Graduate School application form and pay the non-refundable fee.

Computational Engineering Program Requirements

- Have B.S. or M.S. in engineering, natural science, mathematics, or computer science
• Positive recommendation by computational engineering screening committee based on
  o *Computational Engineering Application Form*
  o One-page *Statement of Purpose Form*
  o Three completed *Recommendation Forms*
  o GRE scores required for international students and recommended for U.S. students
    (successful applicants usually score 700 or better on quantitative exam)
  o Meet requirements or qualify for exemption for TOEFL or IELTS exam.

Admission requirements and the admission process are given in the Graduate School Catalog and are discussed on the Computational Engineering website. The website strongly encourages potential but undecided applicants to download and return a *CmE Program Notification of Interest Form* to the program coordinator.

**B. Recruitment**

Many students have been recruited as a result of student responses gained through the Computational Engineering program website, which as of this writing appears as number 1 of 4,490,000 hits in a Google search for “computational engineering”. The website is maintained by the SimCenter and contains extensive, regularly updated materials about the SimCenter and the Computational Engineering graduate program. Some students have been recruited through contacts and referrals from faculty at other universities, as well as referrals from our own students and alumni. Some students have been recruited through occasional recruiting visits to other Tennessee universities.

**C. Enrollment, Demographics, and Degrees Awarded**

As of Fall 2009, the Computational Engineering program had 20 Ph.D. and 15 M.S. students enrolled. A complete list of *SimCenter Graduate Students Fall 2009* with their academic backgrounds is given in Vol. II - Supplemental Materials. Enrollment in the computational engineering program has been consistently higher than that projected when the program was proposed to THEC in 2003. The current Ph.D. enrollment of 20 students is more than double the projected enrollment of 9 students. Eleven new students were enrolled in the Fall 2009 semester, which was made possible in part by funding for the SimCenter expansion. Since its inception in Fall 2004, the program has graduated 10 Ph.D. and 11 M.S. students. Table 1 below summarizes student demographics, and the Chart that follows gives the historical record of enrollment and degrees awarded.

<table>
<thead>
<tr>
<th></th>
<th>Total</th>
<th>%</th>
<th>M.S.</th>
<th>%</th>
<th>Ph.D.</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Students</td>
<td>35</td>
<td>100%</td>
<td>15</td>
<td>43%</td>
<td>20</td>
<td>57%</td>
</tr>
<tr>
<td>Male</td>
<td>30</td>
<td>86%</td>
<td>12</td>
<td>34%</td>
<td>18</td>
<td>51%</td>
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<tr>
<td>Female</td>
<td>5</td>
<td>14%</td>
<td>2</td>
<td>6%</td>
<td>3</td>
<td>9%</td>
</tr>
<tr>
<td>Full-Time</td>
<td>27</td>
<td>77%</td>
<td>13</td>
<td>37%</td>
<td>14</td>
<td>40%</td>
</tr>
<tr>
<td>Part-Time</td>
<td>8</td>
<td>23%</td>
<td>1</td>
<td>3%</td>
<td>7</td>
<td>20%</td>
</tr>
<tr>
<td>U.S. Citizen</td>
<td>25</td>
<td>71%</td>
<td>12</td>
<td>34%</td>
<td>13</td>
<td>37%</td>
</tr>
<tr>
<td>International</td>
<td>10</td>
<td>29%</td>
<td>2</td>
<td>6%</td>
<td>8</td>
<td>23%</td>
</tr>
</tbody>
</table>

**TABLE 1 - Student Demographics**
D. Supervision and Retention of Students

A student’s continuation in a doctoral program depends upon maintenance of satisfactory academic performance and a positive faculty evaluation of the student’s progress. Students with a cumulative GPA of less than 3.0 for all courses graded A-F are placed on academic probation but may continue graduate study so long as each semester’s GPA is 3.0 or greater. Students who fail to meet the degree program’s requirements for satisfactory progress will be placed on academic probation. Course grades less than C or evaluations of NC or NP may not be used on the Doctoral Program of Study. Courses expire after 8 years for credit on the program of study, and the degree must be completed within 6 years after completing the coursework.

**Doctoral Committee** - Each student has a doctoral committee that approves the Doctoral Program of Study, evaluates progress on the research and the final dissertation, certifies the student’s mastery of the necessary skills and knowledge, and assists the student in completing program requirements. Students are reclassified as doctoral degree candidates when the committee has approved a dissertation proposal and other requirements specified in the Doctoral Program of Study. When the written dissertation is completed, the doctoral committee conducts a final oral exam on the research and dissertation (the dissertation defense).
E. Student Orientation and Support
Each new student is given an individual orientation by the Department Head, Dr. Tim Swafford. The orientation includes a New Student Advisement Interview, a SimCenter tour, assignment of cubical space, authorization for SimCenter computer access, and a booklet “Process Information for New CmE Students” explaining administrative processes such as registration and payroll encountered by new SimCenter students.

Early in the first semester, the Department Head also gives a PowerPoint presentation on Orientation for New CmE Students to all new students covering 1) program objectives, 2) building, 3) computer resources, 4) expectations of faculty and students, 5) academic requirements, 6) research requirements, 7) faculty and staff, and 8) the summer project. Students are also given a Handbook for Computational Engineering Students.

One major objective of the educational program is to maintain a working environment that includes students in the team research conducted in the SimCenter. This is accomplished by a mutual expectation among SimCenter faculty and students that students are expected to have meaningful technical interactions with multiple faculty and with other students.

F. Extracurricular Opportunities
The SimCenter has occasional guest seminars on topics in computational engineering that are attended by all students. The SimCenter also has regular visitors related to its research program, and students working in relevant areas often participate in part or all of these meetings. A SimCenter List of Seminars is given in Vol. II - Supplemental Materials.

Students are encouraged to participate in the UTC Graduate Student Association, which is open to all UTC graduate students. Its major events include UTC Research Day, an opportunity for students to propose, prepare and present their research work in posters or other forms of presentation at a judged event, and an Awards Reception where outstanding graduate students are recognized. The Graduate Student Association also distributes Travel Awards to graduate students to participate in professional development each academic year. Activities eligible for funding include presenting research at a conference, gathering data for research, and attending a conference.

The Chattanooga Engineers Club (founded in 1924) holds weekly speaker luncheons on topics relevant to engineering practice, as well as medicine, business, community and other topics. These are open to computational engineering students and faculty.

Numerous professional engineering societies such as AIAA, ASME, IEEE and ASCE have special events in the Chattanooga area with speakers that are occasionally relevant to computational engineering applications.

PART III – FACULTY QUALITY
A. Faculty Credentials
The program has 17 full-time academic and research faculty, all of whom participate in the education program. Faculty members have degrees in mathematics, aerospace, mechanical, computational engineering, and related engineering disciplines. In addition, several senior faculty
members have long-term experience in computational fluid dynamics research, as well as multiple career experiences in industry, academia and government. The faculty has numerous publications and presentations of national and international scope, and several have served as principal investigators for a large number of government- and industry-sponsored research investigations. The younger faculty members have cross-disciplinary educational backgrounds and extensive experience in team-oriented computational engineering research. This background and experience of the younger faculty is a vital ingredient for success of the Ph.D. program. A 2009 list of SimCenter Faculty, Staff and Students and Faculty Resumes are given in Vol. II – Supplemental Materials

Full-Time Faculty and Areas of Expertise

Dr. David L. Whitfield, Professor and SimCenter Director; Ph.D., University of Tennessee (ASE, 1971)
Computational Fluid Dynamics; Solution Algorithms; Unsteady Viscous Flow Applications; Computational Design

Dr. Henry McDonald, Chair of Excellence in Computational Engineering; D. Sc., University of Glasgow (Engr., 1965)
Supercomputing; Information Technology; Artificial Intelligence Applications; Computational Fluid Dynamics; Bio/Information Nanotechnologies

Dr. W. Roger Briley, Professor, Computational Engineering; Ph.D., University of Texas at Austin (ME, 1968)
Computational Fluid Dynamics; Solution Algorithms; Parallel Computing; Viscous Flow and Heat Transfer

Dr. Timothy W. Swafford, Professor and Head, Computational Engineering; Ph.D., Mississippi State University (ASE, 1983)
Computational Fluid Dynamics; Computational Applications in Aerodynamics, Hydrodynamics, and Propulsion

Dr. W. Kyle Anderson, Professor, Computational Engineering; Ph.D., Mississippi State University (ASE, 1986)
Computational Design for Aerodynamics; Steady and Unsteady Flows on Unstructured Meshes; Real Gas Flows

Dr. Lafayette K. Taylor, Research Professor (Research Project Integration); Ph.D., Mississippi State University (ASE, 1991)
Mathematics of Computation; Flux Formulations; Computational Applications in Aerodynamics, Hydrodynamics, and Propulsion

Dr. Steve L. Karman, Jr., Professor, Computational Engineering; Ph.D., University of Texas at Arlington (AE, 1991)
Computational Fluid Dynamics; Internal and External Aerodynamics; Unstructured Mesh Generation and Solution Adaptive Meshing; Design Optimization

Dr. Abdollah (Abi) Arabshahi, Research Professor; Ph.D., Mississippi State University (ASE, 1989)
Unsteady Viscous Flows; Structured Grid Technologies; Computational Applications in Aerodynamics, Hydrodynamics, and Propulsion

Dr. Ramesh Pankajakshan, Associate Research Professor; Ph.D., Mississippi State University (CmE, 1997)
Unsteady Viscous Flow Applications; Parallel Algorithms; Scientific Computing; Computational Design

Dr. Kidambi Sreenivas, Associate Research Professor; Ph.D., Mississippi State University (ASE, 1996)
Unstructured Grid Technology; Unsteady Viscous Flow Applications; Scientific Computing

Dr. Daniel G. Hyams, Associate Professor; Ph.D., Mississippi State University (ME, 2000)
Unstructured Grid Technologies; Parallel Grid Generation; Parallel Algorithms; Integrated Simulation Systems; User Interfaces

Dr. Robert V. Wilson, Associate Research Professor; Ph.D., Old Dominion University (ME, 1996)
Numerical Methods for Free Surface Flows; Unsteady RANS and DES for Turbulent Flows; Prediction of 6DOF Ship Motions and Maneuvering; Verification and Validation Methods

Dr. Robert S. Webster, Associate Research Professor; Ph.D., Mississippi State University (ASE, 2002)
Unsteady Viscous Flows; Structured Grid Technologies; Computational Applications in Aerodynamics, Propulsion, and Turbomachinery

Dr. D. Stephen Nichols, III, Associate Research Professor; Ph.D., Mississippi State University (ASE, 2002)
Unsteady Free-Surface Flow; Surface-Ship Hydrodynamics and Maneuvering

Dr. Chad Burdyshaw, Assistant Research Professor; Ph.D., University of Tennessee at Chattanooga (CmE, 2006)
Design Optimization Techniques; Sensitivity Derivative Calculation; Computational Design

Dr. Sagar Kapadia, Assistant Research Professor; Ph.D., University of Tennessee at Chattanooga (CmE, 2008)
Fuel Cell

Dr. Li Wang, Research Assistant Professor; Ph.D., The University of Wyoming (ME, 2009)
High-order Discontinuous Galerkin Methods; Discrete Adjoint Methods; Shape Optimizations; Error Estimation and Mesh Adaptations
B. Faculty Research

The SimCenter has a strategically planned research program that is focused by multiple research projects involving diverse but computationally related computational engineering problems. This enables the SimCenter and Computational Engineering program to operate as an integrated research and education center, supported by an internally developed and shared software base (Tenasi) and by cost-effective cluster-computing capabilities and dedicated computer resources. The chart below illustrates how diverse complex real-world applications are solved by interdisciplinary teamwork among subgroups of faculty with synergistic individual research specialties.

CHART – Synergy from Teamwork among Faculty and Students

Sources of Funding - Since it was established in 2002, the SimCenter faculty has generated external research funding from many government and private sources:

**Government Agencies**
- Office of Naval Research
- Army Research Laboratories
- U.S. Air Force
- DARPA
- DOE
- NASA
- Health and Human Services
- Small Business Administration

**Companies**
- General Dynamics
- Radiance Technology, Inc.
- Barber-Nichols, Inc.
- Continuum Dynamics
- Aerospace Testing Alliance/AEDC
- ITT/Missile Defense Agency
- Aerotonomy, Inc.
- SPARTA, Inc./AFRL
- Jackson and Tull/AFRL
- Science and Technology Applications
- Riverbend Technology Institute
- Symantec
- Intelligent Light
- Sun Microsystems
The THEC Center of Excellence for Applied Computational Science and Engineering (CEACSE) was established at UTC in 2005. This Tennessee-sponsored Center provides competitively awarded seed funding to faculty and students at UTC to help develop a cohesive and expanding base of multidisciplinary research and education in emerging areas of applied computational science and engineering that can impact the state economy.

SimCenter faculty and students have received numerous small awards (~$40K) for basic research leading to successful proposals for additional sources of funding. This source of funding has also been critical in recruiting experienced research faculty. The CEACSE-funded projects have led to external funding from various government agencies and companies with total awards representing a 5:1 return on CEACSE funds invested in seed funding. During 2009, SimCenter faculty received 12 awards, and 12 SimCenter students have received research assistantships funded by CEACSE.

Publications

The faculty has published about 80 articles during the past 5 years in the following areas:

- Unstructured Grid Generation
- Parallel Solution Algorithms (Navier-Stokes, Maxwell, Shallow-Water, and Boltzmann Equations)
- Sensitivity Analysis and Computational Design
- Ship and Submarine Hydrodynamics and Propulsion
- Aerodynamics of Aircraft, Trucks, and Launch Vehicles
- Liquid and Solid Rocket Propulsion
- Turbomachinery
- Fuel Cell Simulation and Design
- Plasma Discharge
- Two-Phase and Environmental Flows
- Applied Mathematics

AIAA Best Paper Awards

- Steve Karman (Mesh Visualization and Computational Environments, 2006)
- Robert Webster (Air Breathing Propulsion, 2006, Co-Author)

A complete list of publications is given at http://www.utc.edu/Research/SimCenter/publications.php
C. Course Instructors

Computational Engineering Courses

- Dr. Swafford – Intro to CFD, CFD I
- Dr. Anderson – CFD I, CFD II, Computational Design
- Dr. Taylor - Computational Design (Lectures on applied computational mathematics)
- Dr. Karman – Grid Generation, Adaptive and Dynamic Grid Generation, Advanced Programming for Physical Simulation
- Dr. Hyams – Intro to Parallel Algorithms, Parallel Scientific Supercomputing, Advanced Programming for Physical Simulation (Current)
- Dr. Briley – Viscous Flow Theory, Viscous Flow Computation
- Dr. Sreenivas – Practicum for Generating Structured and Unstructured Grids, Practicum for Developing a Solver Using Structured and Unstructured Grids

The program has received consistently high student ratings. The composite student ratings of faculty for the Fall 2008 semester were

- Computational Engineering Program 4.83 out of 5.0
- College of Engineering and Computer Science 4.13 out of 5.0
- UTC 4.48 out of 5.0

While it is to be expected that a graduate-only program would have higher student ratings than averages including predominantly undergraduate students, the Computational Engineering ratings are very high and indicative of strong student approval of course instruction.

Graduate Students who Teach Undergraduate Courses

- Justin Whitt – ENGR 104 (Vector Statics)
- Vincent Betro – MATH 105 (Introductory Algebra), MATH 106 (Intermediate Algebra), MATH 131 (College Algebra), and MATH 145 (Pre-Calculus II)

D. Retirement Outlook

Three of the current 17 full-time faculty members are of retirement age (Whitfield, McDonald and Briley). The senior faculty leaders well recognize the need for a viable leadership-successor plan to ensure that the SimCenter maintains highly talented scholarly leadership for the next 5, 10, and 15 years.

The SimCenter reliance on interdisciplinary teamwork and integration of research and education makes it desirable that any new leadership come from within the SimCenter. The SimCenter currently has a large number of exceptionally talented younger faculty members with leadership abilities, and several currently have internal leadership roles and responsibility in both research and education. These roles include coordination and oversight responsibility for all research projects, technical lead on research programs, interactions with sponsors and potential sponsors, service as editors and chairs of national technical committees, participation at major national conferences through paper presentations and serving as session chairs, developing and teaching courses, and supervising theses and dissertations. As the SimCenter expands, it will recruit some senior people to lead new technical areas, and it will use the recruiting process to identify and recruit people with potential for high-level leadership positions. Ultimately, the SimCenter Director position will need to be filled, and it is planned that this person will emerge from among current faculty or faculty recruited during expansion.
PART IV – TEACHING AND LEARNING ENVIRONMENT

A. Program Objectives

The purpose of the Computational Engineering graduate program is to prepare students to contribute to interdisciplinary computational engineering teams engaged in research, development and the practice of computational engineering. The program has the following working definition of computational engineering:

**Computational Engineering (CmE)** is the development and application of computational models and scientific supercomputing to solve complex physical problems arising in engineering analysis and design. It encompasses development and application of software tools and systems, including physical, mathematical, and geometric modeling, solution algorithms, computer simulations, and visualization, analysis, interpretation, synthesis and use of computed results to solve practical problems.

The program has three educational objectives for its students:

1. Academic preparation in three core areas of computational engineering: a) an engineering application area, b) applied computational mathematics, c) applied scientific computing
2. Preparation for interdisciplinary teamwork to solve complex computational engineering analysis and design problems
3. Preparation for independent research related to solving practical engineering and science problems using computer simulations based on mathematical models of physical phenomena

B. Curriculum

The coursework follows the traditional classroom lecture format. A list of the Computational Engineering courses offered is given below. A *Summary of Courses* and *Syllabi* are given in Vol. II - Supplementary Materials. All courses are offered once per academic year.

**Masters Level Courses**

- ENCM 501 - Introduction to Computational Fluid Dynamics (3 Hours)
- ENCM 510 - Computational Fluid Dynamics I (3 Hours)
- ENCM 534 - Viscous Flow Theory (3 Hours)
- ENCM 516 - Grid Generation (3 Hours)
- ENCM 521 - Introduction to Parallel Algorithms (3 Hours)
- ENCM 590 - Advanced Programming for Physical Simulation (1 Hour)
- ENCM 591r - Special Topics in Computational Engineering (1-3 Hours)
- ENCM 597r - Individual Studies in Computational Engineering (1-9 Hours)

**Doctoral Level Courses**

- ENCM 710 - Computational Fluid Dynamics II (3 Hours)
- ENCM 716 - Adaptive and Dynamic Grid Generation (3 Hours)
- ENCM 723 - Parallel Scientific Supercomputing (3 Hours)
• ENCM 731 - Computational Design (3 Hours)
• ENCM 734 - Viscous Flow Computation (3 Hours)
• ENCM 791r - Special Topics in Computational Engineering (1-3 Hours)
• ENCM 799 - Research and Dissertation (1-9 Hours)

The degree requirements include an individualized program of study including a total of at least 72 hours beyond the bachelor’s degree, exclusive of credit for master’s thesis. These hours must include a minimum of 24 hours of doctoral research and dissertation and a minimum of 48 hours in other courses. These courses must include:

• 24 semester hours of doctoral research & dissertation
• 48 semester hours in other courses
  24 hours numbered 500 or above, at least 12 in CmE
  6 hours numbered 700, excluding dissertation credit
  (One 700-level course can be replaced by 500-level courses by committee petition)
  12 hours Math or CS numbered 400 or above
  Up to 24 hours credit granted for approved coursework from a previous master’s degree

• Program of study must meet core requirements in
  An Engineering Application Area
  Applied Scientific Supercomputing
  Applied Computational Mathematics

C. Teamwork: A Unique Educational Environment

A key goal of the graduate program is to integrate student research experiences with the team research conducted in the SimCenter. Student thesis and dissertation research topics generally support or advance the overall SimCenter research program, and students are expected to observe and participate in the SimCenter team research environment to the maximum extent that this is practical and synergistic. This integration of research and education creates a unique educational environment in which students are mentored through significant interactions with multiple academic and research faculty. The educational objective is to prepare students to contribute their expertise in an environment of teamwork found in the computational engineering workplace.

D. Facilities

The SimCenter occupies a 31,000 sq. ft. research and education facility that was officially opened in November 2003. It is located at 701 East M.L. King Boulevard, adjacent to the UTC campus. This SimCenter facility includes faculty offices, student cubicles, a 1,500 sq. ft. computer room, a conference/meeting room accommodating 25 people, an 80-seat multimedia auditorium, a research library, and other workspace. There are also secure expandable suites of rooms suitable for proprietary and/or classified research; these are currently being used for student cubicles.
Lecture courses are taught in modern multimedia classrooms located on campus in a new Engineering, Mathematics, and Computer Science building opened in 2004. The University also has facilities and support for online classes.

**E. Computers and Support Staff**

The SimCenter’s business, secretarial, graphics, and system administration staff all support the joint operation of the research and education programs.

The SimCenter has had two TOP500 rated clusters that were configured by SimCenter faculty and staff for performance, low cost, and reliable operation using in-house benchmarks. The first cluster (SlideRule), was ranked 90th in the world in November 2005, and the second cluster (PunchCard), was ranked 312th in the world in November 2006.

The SimCenter currently operates a 325 node, dual-processor, dual-core diskless Linux cluster (total of 1300 cores) with 1.3 Terabytes of RAM, 20.8 Terabyte storage system running the IBRIX Fusion file system, and with network connectivity provided by a non-blocking, gigabit-Ethernet, Force10 E1200 switch.

The following computing resources are dedicated to SimCenter use and are operated and maintained by a single system administrator (Wally Edmondson) with two student assistants:
Computer Servers
- 1300 core (325 node) diskless cluster
  - Dual-core Intel EM64T 3.0GHz Xeon processors
  - 4 GB RAM per node
  - Gigabit Ethernet interconnect (576 port Force10 E1200 switch)
- 160 processor (80 node) diskless cluster
  - Intel EM64T 3.2GHz Xeon processors
  - 2 GB RAM per node
  - Gigabit Ethernet interconnect (shares a switch with the larger cluster)
- 64 processor (32 node) diskless cluster
  - Dual Intel 3.2GHz Xeon (32-bit) processors
  - 2 GB RAM per node
  - Gigabit Ethernet interconnect (48 port HP ProCurve switch)
- 12 processor (6 node) diskless cluster
  - Dual Intel 2.8GHz Xeon (32-bit) processors
  - 2 GB RAM per node
  - Gigabit Ethernet interconnect (24 port D-Link switch)
- 2 Sun Fire V880 Servers (one donated by Sun Microsystems for teaching and research)
  - Eight 900 MHz UltraSparcIII processors
  - 16 GB RAM
  - 0.5 Terabytes storage
- 4 processor compute server (Dell)
  - Quad Intel EM64T 3.6GHz Xeon processors
  - 32 GB RAM
  - 292GB high-speed local storage

Desktop Computers
- 18 dual-processor Intel Xeon graphics workstations
- 6 dual-core, dual-processor Intel Xeon graphics workstations
- 3 dual-core, dual-processor AMD Opteron graphics workstations
- 26 Intel Pentium IV workstations
- 13 Sun Blade 150 workstations
- 3 Sun Blade 2000 workstations
- 1 SGI Octane2 (dual MIPS R14K, 2.5 GB RAM)

Infrastructure
- 96 port Cisco Catalyst 4506 GigE switch
- 32 port Brocade Silkworm 3900 SAN switch (2GB/s)
- 4 SunFire v100 servers

Data Storage
- 20.8TB usable disk storage array (DataDirect Networks)
- 10 node dual-processor IBM x335 2.8GHz Xeon storage cluster
- IBRIX Fusion parallel file system
- 600MB/s sustained write throughput
- Available from every computer in the SimCenter
- ADIC Scalar 1000 - tape backup with 64.4TB usable space expandable to 160TB
F. Library Collections and Services

The resources of the UTC Lupton Library are generally adequate to serve the needs of the program, although there is a need for some additional online journal access. The Library houses a circulating book collection of nearly 500,000 volumes, and about 3-4% are applicable to the study of engineering. The Library currently subscribes to over 1,300 print periodicals, including newspapers. Well over 200 were selected by faculty in the College of Engineering and Computer Science to support its programs. In addition, the Library subscribes to numerous electronic journal packages, aggregated sources, and other online tools. These resources are accessible 24/7 from any internet connection through a convenient user interface. Over 1,700 full-text serial titles are relevant to engineering subjects. The primary article-identifying tool supporting engineering research is Engineering Village 2. Additional indexing to journals in the field is available through IEEE Xplore, ASCE: American Society of Civil Engineers, Applied Science and Technology Full Text, SpringerLink Journals, and Instrumentation Abstract Service. The Library offers free interlibrary loan (ILL) service through an electronic ILL management system, ILLiad, which allows users to submit and track the progress of requests online, receive email notification of arrival dates, and receive articles electronically. The State of Tennessee has recently provided one-time funds in the amount of 48 million dollars to plan and build a new library on campus, and UTC has begun planning for this new library. Additional information is available at the Lupton Library web site: www.library.utc.edu.

Finally, the SimCenter has a small but important self-funded research library for internal use, containing many specialized books and periodicals relevant to computational engineering.

PART V – PROGRAM EVALUATION

A. Program Learning Objectives

The program has three learning objectives for outcome assessment:

Objective I. ACADEMIC PREPARATION

Students should receive appropriate and adequate academic preparation leading to competence in the three core areas of computational engineering: a) an engineering application area, b) applied computational mathematics, c) applied scientific computing

Objective II. COMMUNICATION AND TEAMWORK

Students should be capable of making research contributions in an environment of interdisciplinary teamwork to solve complex computational engineering analysis and design problems.

Objective III. INDEPENDENT RESEARCH

Students should be capable of conducting independent research in a computational engineering specialty area, typically related to solving practical engineering and science problems using computer simulations based on mathematical models of physical phenomena

B. Academic Preparation, Comprehensive Exam

Individual programs of study are developed based on each student’s background, interests, and research objectives. The Computational Engineering (ENCM) courses offered collectively contain
very substantial content relating to the core areas of applied scientific computing, applied mathematics of computation, and in the engineering application area of physical and computational fluid mechanics. Two special courses have been taught by invited instructors: Computational Electromagnetics (Walter Hunsicker, Radiance Technologies Inc.) and Principles of Combustion and Computational Applications (Houshang Ebrahimi, Arnold Engineering Development Center). Additional masters-level courses in numerical analysis (MATH 565 and 566) are taught as a Fall/Spring sequence each year. Another courses in numerical solution of partial differential equations (MATH 567) is taught on an as-needed basis. Relevant 400-level courses offered for graduate credit include complex variables (MATH 470) and linear algebra and matrix theory (MATH 412).

At or near the completion of all coursework, students are given a comprehensive examination on material from the three core areas of computational engineering. This review and exam provides a global perspective of course work, especially in relation to the dissertation research project. The exam covers four of the following five major topics: 1) computational fluid dynamics, 2) physical fluid dynamics, 3) mathematics of computation, 4) parallel scientific computing, and 5) grid generation. All students’ exams include material from topics 1) and 3); the other two areas are determined by the student and their major advisor, based on the dissertation research area.

The exam in each topical area is administered by faculty with the appropriate background and experience relevant to the topic. Each exam is administered with written and/or oral components at the discretion of the responsible faculty member. The faculty members responsible for conducting the exams are

- Computational Fluid Dynamics (Dr. T. W. Swafford and Dr. W. K. Anderson)
- Physical Fluid Dynamics (Dr. W. R. Briley)
- Mathematics of Computation (Dr. L. K. Taylor)
- Parallel Scientific Computing (Dr. D. G. Hyams)
- Grid Generation (Dr. S. Karman)

Results of the exams are reported to the Department Head, Dr. T. W. Swafford, and are placed on file in departmental records for each student. The aggregated scores for the 8 graduated Ph.D. students who have taken exams on 4 topics are: A(20), B(11), C(1). The exam has been waived by the committees of 2 graduated Ph.D. students due to their outstanding performance in all coursework and faculty awareness of their knowledge and skills.

**C. Communication and Teamwork**

The second learning objective is addressed by integrating student research experiences with the team research conducted in the SimCenter. This is accomplished by choosing individual student thesis and dissertation research topics that directly contribute to research areas and/or projects at the SimCenter. The existing environment of SimCenter team research then provides a unique and fertile environment for student participation in team research. As their technical interests and research objectives intersect, SimCenter researchers share their specialized expertise with students. The student’s research is thereby guided by multiple experienced researchers, who also provide role models for research. In the process, students develop and improve their communication skills, and they experience team research. Students are also expected to interact with and assist other students as appropriate opportunities arise. This educational process also allows students to work on larger
and more complex research problems than is possible in a more traditional environment in which students are paired with individual professors. This educational process is believed to provide excellent preparation for graduates to contribute their skills in the workplace.

The program monitors and assesses this learning objective and outcomes by obtaining individual evaluations of each student from all SimCenter academic and research faculty, using a Faculty/Student Research Interaction Form that documents both significant/regular and occasional faculty/student interactions that relate specifically to research activities, as opposed to normal student-instructor interactions associated with coursework.

The results of these evaluations are tabulated and filed in departmental records by the Program Coordinator. They are used to monitor and guide student progress toward this outcome. Table 1 gives cumulative tabulated results as of Fall 2009. Both Ph.D. and M.S. (Thesis) students had regular research interactions with about 2 faculty and occasional interactions with an additional 4-5 faculty. Current students with 1 or more years in the program are also developing significant interaction with multiple faculty members. On average, non-thesis students had significantly less faculty interaction and less research progress than other students, which is consistent with their election of the non-thesis option. These results are viewed as excellent outcomes for graduates and evidence of success in meeting this program objective.

<table>
<thead>
<tr>
<th>All Graduates</th>
<th>Number of Faculty</th>
<th>Faculty Evaluations</th>
</tr>
</thead>
<tbody>
<tr>
<td>(highest degree)</td>
<td>Regular Interactions</td>
<td>Occasional Interactions</td>
</tr>
<tr>
<td>Ph.D. (10)</td>
<td>1.80</td>
<td>4.80</td>
</tr>
<tr>
<td>M.S. Thesis (7)</td>
<td>2.29</td>
<td>4.00</td>
</tr>
<tr>
<td>M.S. Non-Thesis (2)</td>
<td>0.50</td>
<td>2.50</td>
</tr>
<tr>
<td>Current Students</td>
<td>1.32</td>
<td>3.05</td>
</tr>
</tbody>
</table>

TABLE 1. – Faculty Evaluations of Research Interactions with Students

D. Independent Research, Dissertation

Each candidate for the doctoral degree must conduct research and present a dissertation on that research that 1) demonstrates a mastery of the techniques of research and 2) makes a very distinct contribution to the field of computational engineering. Each candidate must present a proposal of the dissertation research for approval by the supervisory committee, and defend the research before the committee when the dissertation has been completed.

A Candidacy Form (Program of Study) must be completed prior to the completion of 18 hours of coursework. The student’s major advisor submits a completed candidacy form to the Program Coordinator for review and approval, and the form is then submitted to the UTC Graduate School for approval. Each doctoral student must then successfully complete all courses included in the program of study, pass the preliminary examination, and have the dissertation topic approved by the dissertation committee.

When the research is completed, the candidate prepares and submits a draft of the dissertation to each committee member, and in consultation with the major advisor schedules a final defense through the UTC Graduate School. The final defense includes a public presentation of the
dissertation followed by a defense of the dissertation before the faculty and dissertation committee. The committee either accepts, accepts provisionally (subject to requirements set by the committee), or does not accept the dissertation for credit toward the degree requirements. The Program Coordinator records the outcome of the defense and submits the form to the Graduate School.

The Program Coordinator subsequently consults with faculty and records an anecdotal assessment of the dissertation quality and student research expertise for the purpose of evaluating program outcomes. The anecdotal assessments for the 10 Ph.D. students who have graduated are: A(7), B(3). Analogous informal assessments for the 11 M.S. students who have graduated are: A(6), B(2), non-thesis option (3).

E. Evaluation of Curriculum, Revision Activities

**Evaluation Process** - The Program Coordinator consults with faculty to review and evaluate the program curriculum twice yearly, usually after the fall semester and during the summer. The evaluation process is informal and based on discussions and appropriate working groups when needed.

Being interdisciplinary, the program has considerable diversity of background in its entering students, and no undergraduate discipline provides an ideal background in all three core areas of computational engineering.

**Non-Engineering Majors** – Since computational engineering is a new interdisciplinary degree program that is open to students with various science and engineering baccalaureate degrees, the program has tried to develop effective methods for screening applicants and for advising and providing adequate orientation for new students. Not surprisingly, it has been found that students with mechanics-based engineering degrees generally had the best backgrounds for the computational engineering program. However, students with majors in physics and mathematics have also had excellent background preparation except for a lack of experience in engineering problem solving. These students have been asked to take two or three undergraduate courses in engineering mechanics (usually statics, fluid mechanics, and thermodynamics) as additional non-credit courses to provide needed background in engineering science and engineering problem-solving skills. The program has received very good support from Dr. Mike Jones, one of the College’s most experienced and successful mechanical engineering teachers, to accommodate these students in his undergraduate engineering mechanics courses. This approach has worked well in providing non-engineering graduate students with adequate background in engineering science and problem solving.

**Basic Computational Skills** - It became evident early in the program’s operation that a high percentage of incoming students from all majors lacked sufficient background with the Linux operating system and in scientific programming to prepare them for some of the projects assigned in courses. In response, Dr. Karman developed a new one-hour course taken by all new students, to provide basic orientation and instruction in computational and computer skills needed early in the program. This course was implemented in 2006 and has successfully addressed this problem.

**Mastering Scientific Programming** – More recently, the faculty observed that some students who were otherwise performing well were having trouble completing some of the more advanced programming-intensive projects both in courses and in research. The faculty decided that even students who entered the program with some background and confidence in computer programming
do not have the actual working skills needed to perform at levels required by the curriculum. In response, the faculty decided that all new students should receive early practical experience in scientific programming for typical problems encountered in computational engineering classes. Dr. K. Sreenivas developed and has taught two seminar-styled special-topics courses during the summer 2008 and 2009 semesters:

- Practicum in Generating Structured and Unstructured Grids
- Practicum in Developing a Solver for Inviscid Flow Using Structured and Unstructured Grids

These courses are designed to provide practical experience in formulating a numerical algorithm, implementing the algorithm in software, compiling and debugging the software, and interpreting computed results. These courses will be offered in the summer 2010 semester as formal Special Topics courses (ENCM 591r), and will likely be proposed as permanent courses.

**Mathematics Review Test** – The faculty has noticed that a small number of students have had difficulty with various mathematical manipulations and derivations requiring skills that should have been mastered in undergraduate mathematics courses. Beginning in the Fall 2010 semester, a mathematics review test will be given during the new-student orientation and advisement process to provide early diagnosis of any weaknesses relevant to the curriculum.

**New Courses Developed**

Since the program was started in 2002, six new courses have been developed and added to the original five courses offered when the program began:

- ENCM 590 - Advanced Programming for Physical Simulation (1 Hour, Karman, Hyams)
- ENCM 534 - Viscous Flow Theory (3 Hours, Briley)
- ENCM 516 - Grid Generation (3 Hours, Karman)
- ENCM 723 - Parallel Scientific Supercomputing (3 Hours, Hyams)
- ENCM 731 - Computational Design (3 Hours, Anderson)
- ENCM 716 - Adaptive and Dynamic Grid Generation (3 Hours, Karman)

Three other utility courses were also added:

- ENCM 591r - Special Topics in Computational Engineering (1-3 Hours)
- ENCM 597r - Individual Studies in Computational Engineering (1-9 Hours)
- ENCM 791r - Special Topics in Computational Engineering (1-3 Hours)

**Possible New Courses** – The faculty is currently considering possible new courses that could be developed to expand and enhance the curriculum. The faculty believes that new research capabilities are needed in computational structural dynamics and in advanced finite-element analysis, and the SimCenter plans to hire new faculty that would develop and teach in these areas. Another idea under consideration is to develop a “capstone” course covering Current Topics in Computational Engineering, which would consider advanced specialized topics that would both support diversification of the SimCenter’s research capabilities and also give students guidance in reading and evaluating current publications. The existing faculty is also considering development of other new courses with topical coverage of advanced compressible flow, heat transfer, turbulence modeling, and numerical solution of linear, nonlinear, and ordinary differential equations.
Exit Interviews and Follow-Up Feedback from Graduates - The faculty has given some thought to soliciting feedback from graduates on how their education prepared them to contribute and compete in the workplace. At present, the program has not implemented any systematic approach to this, although there is occasional feedback from former students.

Anecdotally, there have been some positive and enthusiastic comments relating to the program’s emphasis on its interdisciplinary curriculum, real-world problems, and teamwork; for example:

- One student was emphatic in how the real-world aspect of his education had given him a competitive advantage over other students in job interviews.
- Another student mentioned that the skills he learned working independently but in an interdisciplinary team environment were beneficial in day-to-day work activities.
- Another graduate said that the more he talked to people who used commercial codes, the more appreciative he was of the education he received at the SimCenter.

F. Completion Rates, Student Placement

Completion Rates

The Ph.D. program has enrolled a cumulative total of 34 students. Of these, 10 have graduated, 20 are currently enrolled, and 4 have withdrawn (1 job-related, 2 by choice, and 1 for other reasons).

The M.S. program has enrolled a cumulative total of 35 students. Of these, 11 have graduated, 15 are currently enrolled, and 9 have withdrawn (3 job-related, 3 by choice, 1 changed to the mechanical engineering option, and 2 for other reasons).

Placement History

Ph.D. Graduates (10)
- (1) Boeing Phantom Works, St. Louis MO
- (1) Exa Corp. Cambridge MA; currently at Northwestern University, Evanston IL
- (1) GE Aircraft; Williams Engine; currently at Belcan Engine Group, Cincinnati OH
- (1) Radiance Technologies, Chattanooga TN
- (1) Oak Ridge National Lab, Oak Ridge TN
- (2) Assistant Research Professor at UTC SimCenter, Chattanooga TN
- (1) Post-Doctoral Fellow, Univ. Victoria, British Columbia, Canada
- (2) Left the U.S.

M.S. Graduates (11)
- (7) Continued in the PhD program (2 have graduated)
- (1) Science Applications International Corp., Huntsville AL
- (1) High-School Football Coach and Math. Teacher, Hendersonville TN
- (2) Other
G. External Board of Advisors

The SimCenter, Computational Engineering program, and the CEACSE are fortunate to share a very distinguished Advisory Board that meets when needed, typically once or twice per year:

- Bill Stacy (Chair), President/Headmaster, Baylor School, TN
- David Turek, IBM, Vice President for Deep Computing, Poughkeepsie, NY
- David Keyes, Professor, Columbia University, NY
- Dale Anderson, Vice President for Research, University of Texas at Arlington, TX, retired
- James Fein, Director, Naval Surface Warfare Center, Bethesda MD, retired
- Eric McFarland, Project Manager, NASA Glenn Research Center, OH, retired
- C.T. Cozart, Vice President for Marketing, Chevron Corporation, retired