Integration of Simulation Technology into Undergraduate Engineering Courses and Laboratories

Fred Stern, Tao Xing, Marian Muste, Don Yarbrough[1]
Alric Rothmayer, Ganesh Rajagopalan[2]
David Caughey, Rajesh Bhaskaran[3]
Sonya Smith[4]
Barbara Hutchings[5]

Abstract

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Simulation technology is integrated into undergraduate engineering courses and laboratories through the development of teaching modules (TM) for complementary computational fluid dynamics (CFD), experimental fluid dynamics (EFD), and uncertainty analysis (UA). TM include three parts: (1) lectures on CFD and EFD methodology and standard procedures and UA; (2) CFD templates for academic use of commercial industrial CFD software; and (3) exercise notes for use of CFD templates and complementary EFD and UA. The commercial industrial CFD software is FLUENT http://www.fluent.com/, which is widely used in many industries and universities and is a partner in the project. Initial TM are based on those developed as "proof of concept" at The University of Iowa from 1999 to present, as updated and currently being used (http://www.icaen.uiowa.edu/~fluids/). Recently, project expanded under sponsorship National Science Foundation Course, Curriculum and Laboratory Improvement - Educational Materials Development Program to include faculty partners from colleges of engineering at large public (Iowa and Iowa State) and private (Cornell) and historically minority private (Howard) universities for collaboration on further development TM, effective implementation, evaluation, dissemination, and pedagogy of simulation technology utilizing web-based techniques. The evaluation plan includes collaboration with faculty from The University of Iowa, College of Education, Department of Psychological and Quantitative Foundation and Center for Evaluation and Assessment. Paper describes the overall objectives, approach, results, and conclusions based on the first-years efforts.

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[1] The University of Iowa
[2] Iowa State University
[3] Cornell University
[4] Howard University
[5] Fluent Inc.

I. Introduction

Undergraduate engineering curriculum is changing in response to rapid advancements in simulation technology. Use of simulation-based design and ultimately virtual reality will eventually dominate engineering practice in comparison to current reliance on experimental observations and analytical methods. It is not unreasonable to expect that a major shift will occur in how the scientific method forms a basis of conceptual truth, a shift from reliance on observations, based on experiments, to reliance on logic, based on simulation. With profound similarities and differences to transition from Aristotelian to Galilean scientific methods, as occurred in 16th century. These changes take place as engineering becomes global and procedures subject to international standards. Engineering simulation technology covers broad range from computerized systems [1-4] to solutions of physics based initial boundary value problems. Of interest here is the latter; specifically, computational fluid dynamics (CFD). CFD is a widely used tool in fluids engineering with many specialty and commercial CFD codes through out the world covering many disciplines. One major obstacle in using CFD is lack of trained users.

Recently, educators have begun integration of CFD into undergraduate fluid mechanics and senior design courses using both specialty and commercial codes [5,6,7]. In a few cases, CFD was combined with experimental fluid dynamics (EFD) laboratories [8,9]. At the same time, EFD laboratories have undergone improvements for modern measurement systems [10,11] and use of standard uncertainty analysis (UA) procedures [12,13]; and Internet technology has impacted teaching through web based instruction [14,15,16], remote experiments [17], studio model courses [18], electronic text books [19], and distribution via CD-ROM [20,21].

Present project concerns integration of simulation technology into undergraduate engineering courses and laboratories through the development of teaching modules (TM) for complementary CFD, EFD, and UA. Knowledge of all three is essential along with optimization methods for realization of physics-based simulation based design. TM include three parts: (1) lectures on CFD and EFD methodology and standard procedures and UA; (2) CFD templates for academic use of commercial industrial CFD software; and (3) exercise notes for use of CFD templates and complementary EFD and UA. The commercial industrial CFD software is FLUENT http://www.fluent.com/, which is widely used in many industries and universities and is a partner in the project. Initial TM are based on those developed as "proof of concept" at The University of Iowa from 1999 to present, as updated and currently being used http://www.icaen.uiowa.edu/~fluids/). Recently, project expanded under sponsorship National Science Foundation Course, Curriculum and Laboratory Improvement - Educational Materials Development Program to include faculty partners from colleges of engineering at large public (Iowa and Iowa State) and private (Cornell) and historically minority private (Howard) universities for collaboration on further development TM, effective implementation, evaluation, dissemination, and pedagogy of simulation technology utilizing web-based techniques. The evaluation plan includes collaboration with faculty from The University of Iowa, College of Education, Department of Psychology and Quantitative Foundation and Center for Evaluation Assessment. The present paper describes the overall objectives, approach, results, and conclusions based on the first-years efforts.

II. Development of Teaching Modules

Simulation based design must be physics based to gain credibility and wide spread use. The research and development process involves complementary CFD, EFD, and UA; therefore, TM developed to mirror this process. However, TM also developed so that CFD, EFD, and UA components can be used separately or even as in-class demonstrations.

Fluid mechanics courses are included in the curriculums of most engineering programs with both program required and technical elective courses. Program required courses are at both the introductory and advanced levels, whereas technical elective courses are usually at advanced levels. Often introductory level courses are required by more than one program (e.g., mechanical, civil, and bio engineering departments). Most introductory courses are textbook based with emphasis on analytical fluid dynamics (AFD) with or without EFD. EFD used primarily to demonstrate flow physics with limited consideration of EFD methodology and UA. CFD seldom included. Advanced level courses are either AFD with or without CFD and/or EFD assignment or EFD including methodology and in some cases UA.

TM are being developed to meet all these situations, but are recommended for use in complementary fashion. Initial focus is for introductory level courses but intention and timetable includes use at the advanced level. Philosophy of TM is to provide teaching aids that supplement but do not replace faculty lectures. Pedagogy is for faculty to provide appropriate background discussion depending on course level and implementation and use TM as teaching aids for lectures and detailed procedures for complementary CFD, EFD, and UA laboratory assignments. TM is succinct, easy to use, especially accessible to undergraduate students, and readily integrated into current usual classroom and laboratory teaching materials for undergraduate fluid mechanics courses and laboratories.

Specifically, TM under development for pipe, airfoil, nozzle, and cylinder flow for use in teaching program required introductory fluid mechanics and thermal/fluid, gas dynamics, and aerodynamics laboratory courses. Table 1 summarizes and provides hyperlinks for TM used in introductory fluid mechanics course.

Table 1. TM used for introductory fluid mechanics course (EFD/CFD Lab materials)

Lecture	Other Docs	Lab1: Viscosity	Lab 2: Pipe Flow	Lab 3: Airfoil
EFD lecture	EFD UA Report EFD UA Theory EFD UA Example Lab report instructions	Pre lab1 EFD 1 Lab1_UA Instructions_UA	Pre lab2 EFD 2 Lab2_UA Instructions_UA	Pre lab3 EFD 3 Benchmark Data Instructions_UA
CFD lecture	CFD lab report instructions Sample Report	None	Pre CFD lab1 CFD lab1	Pre_CFD lab2 CFD lab2

A. EFD and UA

The goals of the EFD and UA laboratories are to teach students EFD and UA methodology and procedures through classroom lectures and use of modern facilities (pipe stands, wind tunnels) and measurement systems (load cells, pressure transducers, sensors and computerized data acquisition and reduction) for complementary experimental and computational laboratories, including teamwork and presentation of results in written and graphical form. Focus is on "hands-on" experience with EFD and UA as a "tool" for solving fluid mechanics problems, validation of CFD and AFD results, analysis results regarding fluid physics, and enhancement of classroom lectures. EFD lecture covers basic EFD philosophy, types of experiments, test design, data reduction equations, measurement systems, and uncertainty analysis. Spreadsheets are provided to the students to facilitate their uncertainty analysis. Assignments cover purpose, test design, data reduction equations, measurement systems, data acquisition and reduction, uncertainty analysis, benchmark data, and analysis and discussion results. Institutional investment in facilities, measurement systems, and support staff is essential for meeting goals of EFD and UA laboratories.

B. CFD and UA

The goals of the CFD and UA laboratories are to teach students CFD methodology (modeling and numerical methods) and procedures (CFD process) through classroom lectures and use of commercial industrial software for complementary experimental and computational laboratories, including teamwork and presentation of results in written and graphical form. Focus is on "hands-on" experience with CFD and UA as a "tool" for solving fluid mechanics problems, including validation using EFD data and uncertainties, analysis results regarding fluid physics, and enhancement of classroom lectures. CFD lecture covers definition and use of CFD, modeling, numerical methods, and CFD process, including geometry, flow conditions and properties, models, initial and boundary conditions, grid generation, numerical parameters, solution, post processing, and UA. Assignments cover purpose, simulation design, and application CFD process. Institutional investment in appropriate CFD software is essential for meeting goals of CFD and UA laboratories. It's best for students to use commercial industrial software, as they likely will use it as professionals; however, it's also best if a learning interface is used to facilitate students learning CFD process. Faculty and FLUENT are collaborating on development of learning interface.

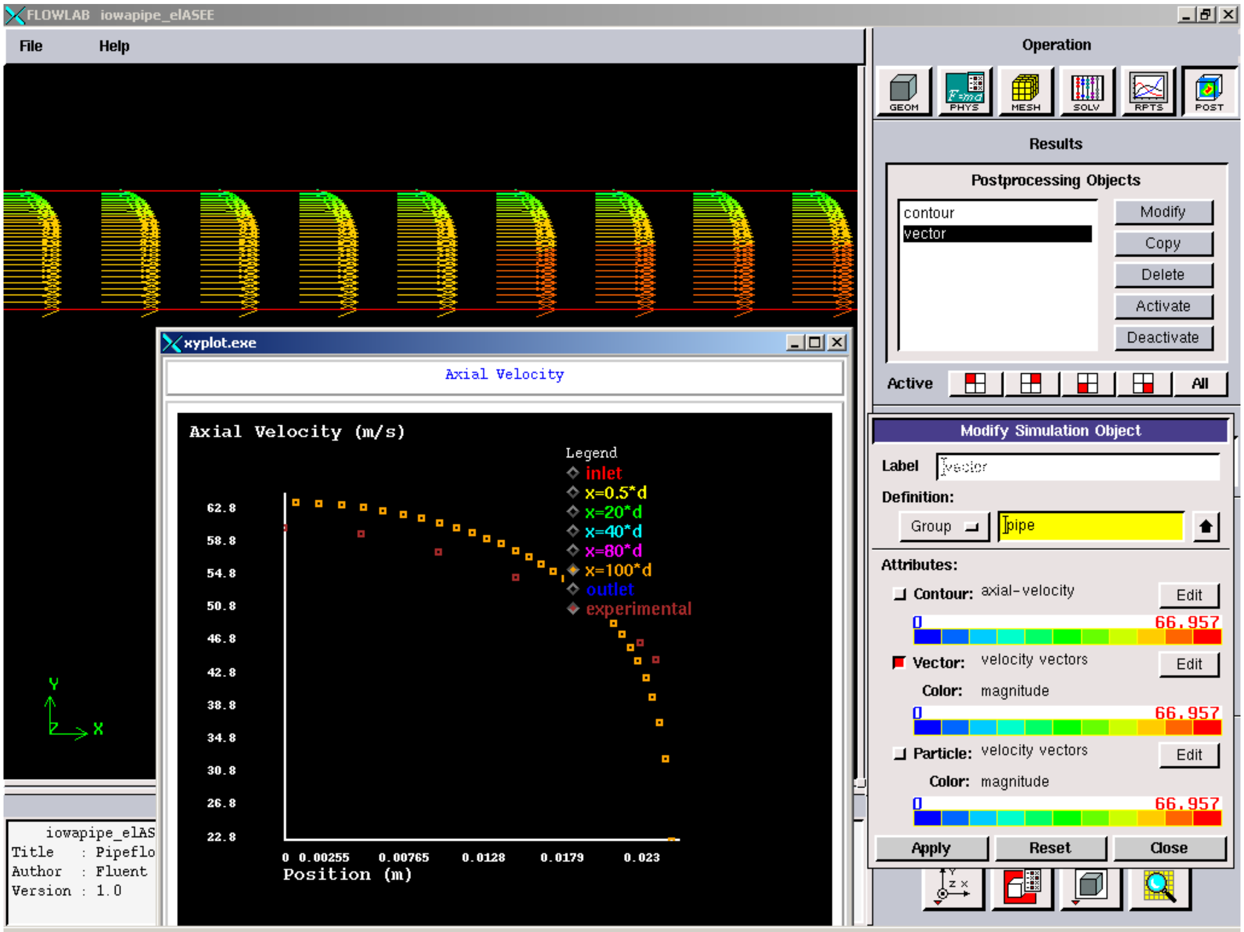
III. Collaboration

A. Faculty

Faculty meetings are held for discussions on further development TM, effective implementation, evaluation, dissemination, and pedagogy of simulation technology utilizing web-based techniques. Different faculty took primary responsibility and expert review for each of the TM and EFD, CFD, and UA lecture notes. Pipe and airfoil TM will be site tested at as many of the different universities as possible using common evaluation plan. Project activities summarized on project web site http://www.iihr.uiowa.edu/~istue/.

B. FLUENT

The CFD templates for academic use of commercial industrial CFD software used in the present project are being developed by FLUENT under product name "Flowlab," with collaboration faculty. Flowlab (http://www.flowlab.fluent.com/) is a CFD-based educational software package, which allows students to solve predefined CFD exercises. Initially CFD templates and exercise notes are being developed for pipe, airfoil, nozzle, and cylinder flow to be used in teaching introductory level courses and laboratories. Figure 1 shows CFD template for pipe flow at specific step of CFD process. Pedagogy for CFD templates is to both teach and provide students with "hands-on" experience with CFD process. Buttons in upper right hand corner step students through CFD process: geometry, physics (flow conditions and properties, modeling, initial and boundary conditions), mesh, solve (numerical parameters), reports (iterative convergence), and post processing (flow visualization, analysis, verification, validation using imported EFD data and uncertainties). Button options are predefined for student exercises using hierarchy system whereby introductory level have fewer options and advanced level more options such that by third level students essentially using FLUENT.



Label: vector
Definition: Group pipe
Attributes:
☐ Contour: axial-velocity
0 66.957
■ Vector: velocity vectors
Color: magnitude
0 66.957
☐ Particle: velocity vectors
Color: magnitude
0 66.957

iowapipe_elAS
Title : Pipeflo
Author : Fluent
Version : 1.0

Figure 1 CFD template for pipe flow

IV. Implementation

Implementation planned with priority to site testing pipe and airfoil flow TM at as many partner universities as possible, including similar evaluation. Integration of TM into undergraduate engineering courses and laboratories depends on whether CFD, EFD, and UA components are used complementarily or separately and type and level of course. Following provides descriptions of implementation for an introductory fluid mechanics course at Iowa and for aerodynamics and gas dynamics laboratory courses at Iowa State.

A. Iowa

The introductory fluid mechanics course is a 4-semester hour junior level course attended primarily by mechanical, civil and environmental, and bio- engineering students. Course was originally organized 3-semester hour AFD and 1 semester hour EFD. The approach was to reduce number of EFD experiments replacing with EFD and UA and complementary CFD simulations. AFD, EFD, and CFD taught as complementary tools of engineering fluid mechanics. UA provides quality control. Class lectures were used primarily for AFD. Laboratory time was used for EFD and CFD lectures on methodology and UA and complementary EFD and CFD labs. Note that complementary CFD tended to place more stringent requirements on quality of EFD results, which was only achievable through use of UA. Class was also reorganized for web based teaching and distribution of materials (http://css.engineering.uiowa.edu/~fluids/). Table 1 summarizes and provides hyperlinks for TM used in introductory fluid mechanics course. EFD, CFD, and UA laboratories scheduled for whole semester in parallel with AFD lectures. EFD lecture given first followed by EFD 1, which is a tabletop experiment emphasizing physics of fluid properties and UA procedures. Next EFD and CFD and UA are done complementarily for pipe and airfoil flow. Spreadsheets are used to facilitate the experimental UA. Students work in groups with separate laboratory reports for EFD and CFD.

B. Iowa State

Iowa State University began work this past summer on the integration of FlowLab and Computational Fluid Dynamics (CFD) methodologies into selected undergraduate Aerospace Engineering laboratory courses as part of the cooperative activity with the other authors on this paper. Specifically, CFD was introduced into our AerE243L Aerodynamics Laboratory and AerE311L Gasdynamics Laboratory (these are required courses at the sophomore and junior year). These labs present a unique challenge for CFD, since they are not stand-alone laboratory courses with a large amount of available and adjustable time. These two courses are effectively the laboratory components of lecture courses, and are meant to supplement the lecture courses by exposing students to the practical phenomenon and concepts, which are introduced in a more theoretical setting within the lecture course. In other curriculum, such labs are often contained within the lecture courses. Primarily for course management reasons, our department retains the courses as separate 0.5 credit hour labs, which have the lecture courses as co-requisites. The two labs being tested in this study are a low speed aerodynamics lab and a high-speed gas dynamics lab. In the case of the gas dynamics lab, the complementary lecture course covers basic thermodynamics for about half the course and fundamental gas dynamics for the other half, i.e.

one-dimensional flow, shock waves, Prandtl-Meyer flow, etc. The lab is 0.5 credits and meets for one half a semester. This means that each student in the lab has one contact hour each week for a total of seven weeks (i.e. there are seven one hour meetings). A large number of students take this lab. This semester we had four sections with 14-15 students in each section. Sections are further subdivided into groups of 4-5 students, with each group performing all the experiments, theoretical calculations and CFD for the lab. Within the seven meetings, the students run two inter-related experiments. All the experiments use a set of three interconnected 120psi high-pressure tanks connected to a common de-Laval nozzle. The experiments include: 1) a comparison of isentropic and isothermal models with a transient blow-down of the tanks, 2) identification of first, second and third critical conditions, and 3) comparison of wall pressures predicted from one-dimensional theory with measured pressures in the nozzle at selected pressure ratios. The laboratory is taught in the second half of the semester so as to take advantage of background in the lecture class from the first half of the semester. Needless to say, the class schedule is fairly tight and adding a CFD component to the class is difficult. There are two main reasons for adding CFD to these labs. The first is to expose students to CFD early in the curriculum so that they are aware of the technology and have seen it several times before the senior year, when they will make much more extensive use of computational methods and CFD. During the senior year, students also have the option of taking a senior elective in CFD as well as one of two introductory graduate courses on the subject, which are offered every year. The second reason for introducing CFD is our belief that there is somewhat of a disconnect between the one-dimensional theory and the experiment. Part of this is the difficulty in having the students make the conceptual connection between the rather abstract one-dimensional equations and the real three-dimensional experiment. The other issue is that while the one-dimensional theory compares reasonably well with experiment for certain cases, it does not compare as well as we would like for slightly less than half of the experiments. We believe that this is due to rapid geometry changes and viscous shock boundary layer interactions, which are not modeled in the one-dimensional theory. Our hope is that a more accurate CFD model can bridge the conceptual and accuracy gaps we are seeing in the lab.

This past summer, FlowLab was set up in the lab using a stand-alone machine on a portable cart, along with an RGB projection system. We purposefully used a low end PC in order to test the viability of running the CFD software on an inexpensive and easy to maintain environment. FlowLab was integrated into the class using a 30-minute lecture that combined an overview of CFD with a lecture on how to use the FlowLab software module (flow through a de Laval nozzle in this case). Due to time constraints we used a de-Laval nozzle module already created by Fluent (which did not have quite the same geometry as our nozzle). The students were then given approximately one lab class in which to run the software and generate results for comparison with experiment and one-dimensional theory. In essence, we lost about one and a half classes out of seven, which were accommodated by carefully coordinating and streamlining the other components of the lab. The results were very encouraging. The FlowLab software was simple enough to use that students were able to use it independently with a minimal amount of training. While FlowLab presents CFD as somewhat of a "black-box", the level of detail presented to the students by the software was appropriate for their level and our course. It should be noted that FlowLab can be customized to any level of desired complexity by the module developer. Furthermore, the student had control over grid resolution via fine, medium and course grid toggles and were able to compare solutions on these different grids, as well as vary nozzle parameters (such as pressure ratio). An inadvertent bonus from the use of the FlowLab module created by Fluent was the fact that the module imposed outflow boundary conditions right at the nozzle exit, which means that the module could not compute cases involving oblique shocks or expansion waves outside the nozzle, which were required as part of the lab. The module still gave answers for these cases, and this was a good case study showing that an incorrectly posed CFD problem will not give a correct solution.

V. Evaluation

A. Iowa

The evaluation plan includes collaboration with faculty from The University of Iowa, College of Education, Department of Psychological and Quantitative Foundation and Center for Evaluation and Assessment. The initial evaluation plan specifically for the introductory fluid mechanics course was developed and administered Fall Semester 02. Detailed course goals were developed for both lectures and laboratories and cross-referenced to ABET outcomes identifiers. Similarly a detailed student survey was prepared with 52 general course and 21 EFD, CFD, and UA questions with which students could agree or disagree on a 6 point scale: [strongly agree (6) to strongly disagree (1) or "no opinion"]. In addition, the survey collected routine demographic data and other comments or suggestions. Forty-five students responded to the survey anonymously.

The EFD, CFD, and UA questions and summary student responses are provided in Table 2. Mean values and standard deviations range from 3.98-4.91 and .81-1.3 respectively. Thus, students on average moderately to mildly agree that the EFD, CFD, and UA laboratories improved their knowledge, understanding and skills, as specified in the evaluative statements. The detailed survey included 28 student comments, which are also useful for assessing student attitudes and developing strategies for improving the labs. Table 2 presents the percentages of students providing each response from Strongly Agree to Strongly Disagree (or No Opinion) for each of the following 21 statements, as well as mean and standard deviations (SD) for each item when numerically scored from 6 (Strongly Agree) to 1 (Strongly Disagree).

Table 2. Survey Results for Each Item: Percentages of Respondents Choosing Each Response, Item Means and Standard Deviations[1]

Questions	SA	A	a	d	D	SD	NO	Mean	SD
I have a basic understanding of experimental and uncertainty analysis methodology and procedures.	**9.1**	**36.4**	**36.4**	**9.1**	**4.5**	**4.5**	**0**	**4.23**	**1.18**
I can present results from EFD laboratories in written and graphical Form.	**22.7**	**47.7**	**25**	**4.5**	**0**	**0**	**0**	**4.89**	**0.81**
I can conduct experiments in modern facilities, such as pipe stands and wind tunnels.	**27.3**	**38.6**	**31.8**	**2.3**	**0**	**0**	**0**	**4.91**	**0.83**
I can conduct experiments using modern measurement systems, including pressure transducers and Pitot probes and computer data acquisition and reduction.	**25**	**29.5**	**31.8**	**13.6**	**0**	**0**	**0**	**4.66**	**1.01**
I can conduct UA for practical engineering experiments, including estimates for bias, precision limits, and total uncertainties.	**9.1**	**27.3**	**34.1**	**18.2**	**4.5**	**6.8**	**0**	**3.98**	**1.28**
I can identify most important error sources in practical engineering experiments.	**6.8**	**40.9**	**34.1**	**13.6**	**2.3**	**0**	**2.3**	**4.37**	**0.90**
I can use benchmark data and UA to assess the accuracy	**22.7**	**47.7**	**22.7**	**4.5**	**0**	**0**	**2.3**	**4.91**	**0.81**

of experimental results.									
I can use EFD data for validation of CFD results.	**29.5**	**38.6**	**22.7**	**9.1**	**0**	**0**	**0**	**4.89**	**0.95**
I can analyze EFD results to gain increased understanding of fluid physics.	**18.2**	**43.2**	**34.1**	**4.5**	**0**	**0**	**0**	**4.75**	**0.81**
I can relate EFD results to fluid physics and classroom lectures.	**22.7**	**31.8**	**40.9**	**2.3**	**0**	**0**	**2.3**	**4.77**	**0.84**
I have a basic understanding of CFD methodology and procedures.	**13.6**	**31.8**	**40.9**	**11.4**	**2.3**	**0**	**0**	**4.43**	**0.95**
I can use Flowlab for solving laminar and turbulent pipe flow and inviscid and viscous airfoil flow.	**29.5**	**27.3**	**34.1**	**9.1**	**0**	**0**	**0**	**4.77**	**0.99**
I can present results from CFD simulations in written and graphical form.	**29.5**	**31.8**	**31.8**	**6.8**	**0**	**0**	**0**	**4.84**	**0.94**
I can run Flowlab and implement the CFD process for laminar and turbulent pipe flow.	**29.5**	**34.1**	**27.3**	**6.8**	**2.3**	**0**	**0**	**4.82**	**1.02**
I can run Flowlab and implement the CFD process for inviscid and viscous airfoil flow.	**29.5**	**29.5**	**31.8**	**6.8**	**2.3**	**0**	**0**	**4.77**	**1.03**
I can evaluate iterative convergence through setting iterative convergence criteria and analysis of solution residuals.	**25**	**29.5**	**36.4**	**4.5**	**4.5**	**0**	**0**	**4.66**	**1.06**
I can evaluate grid convergence through analysis of solutions on coarse, medium, and fine grids.	**22.7**	**38.6**	**22.7**	**13.6**	**0**	**2.3**	**0**	**4.64**	**1.12**
I can transform the experimental data files of EFD labs into Flowlab format and import those files into Flowlab.	**15.9**	**31.8**	**25**	**18.2**	**6.8**	**0**	**2.3**	**4.33**	**1.17**
I can compare the computational results with the experimental data and analyze the differences.	**22.7**	**43.2**	**27.3**	**6.8**	**0**	**0**	**0**	**4.82**	**0.87**
I can perform analysis of CFD results through investigations of developing vs. fully developed pipe flow, laminar vs. turbulent flow and turbulence modeling, inviscid vs. viscous flow, and flow field visualization.	**20.5**	**29.5**	**36.4**	**9.1**	**0**	**4.5**	**0**	**4.48**	**1.19**
I can relate the CFD results to fluid physics presentations in written materials and the classroom lectures.	**11.4**	**34.1**	**45.5**	**4.5**	**0**	**2.3**	**2.3**	**4.47**	**0.93**

[1] Survey results for each item: Numbers in columns are percentages of respondents choosing each item, item means and standard deviations. Categories of responses are numerically represented as follows: SA=6; A=5; a=4; d=3; D=2; SD=1. "No Opinion" responses are not included in the computation of means and standard deviations. For means and standard deviations, N = 44 or 43.

B. Iowa State

We gave the students a brief survey at the end of the course, primarily to gauge student interest and to determine whether or not there were any major pitfalls in our use of the software. The only major pitfall we encountered was a uniform desire by students to have the software available outside of class. The results are summarized in Table 1. We were quite surprised by the fact that we had almost 100% positive response to this activity. Most of the students believed that the CFD was interesting and helped them to understand concepts presented in the class. From separate comments turned in by the students, we found that the visualization aspect of CFD was perceived by the students to be the most helpful aspect of the software. A significant number of students were disappointed that we did not spend more time on CFD and one student asked for separate access to the software to do other projects outside of class. Given the large number of students taking this class, and despite the fact that we only had one PC and we only allowed students to run simulations during the laboratory class time, we were easily able to complete the CFD simulations for all student groups in a reasonable period of time. This is primarily due to the fact that we restricted ourselves to steady 2D simulations, which were fairly straightforward. It is to be expected that more complex simulations would cause time problems. Each student group was able to run 5-6 CFD cases and generate comparisons with experiment and one-dimensional theory. In general, the CFD results showed enough improvement over one-dimensional theory (even given differences in nozzle geometry) that we believe the CFD will prove to be a valuable intermediate tool which can complement the one-dimensional theory and experiment.

Overall, we have been pleasantly surprised by the ease with which we could integrate the CFD simulations into the laboratory classes, even given the severe time constraints under which we were operating. The FlowLab software performed exceptionally well and the student response was much better than we had expected. The next task we will face in these labs is attempting to do a similar cost-effective integration of the uncertainty analysis concepts discussed in other sections of this paper.

Table 3. Summary of course evaluations.

a. Including CFD in the lab was a beneficial and worthwhile experience

92% agree 8% disagree

b. Was the FLOWLAB software useful for a short introduction to CFD?

100% agree 0% disagree

c. Was the content of the CFD overview lecture

4% too in-depth 79% just right 17% not enough

VI. Conclusions and Future Work

Project successful in developing, implementing, and evaluating TM for introductory level fluid mechanics courses and laboratories. Evaluation results helpful in developing strategies for improved TM and more effective implementation. Student anonymous responses suggest students agree EFD, CFD, and UA labs were helpful to their learning fluid mechanics and important “tools” that they may need as professional engineers; however, they would like that learning experience to be as “hand-on” as possible.

Future work will focus on site testing along with improvements to the introductory level TM in conjunction with initial development advanced level TM. EFD and UA labs will be improved for increased student “hands on” involvement through, e.g., student installation of model and measurement systems also making the UA more interesting and performing calibrations. CFD and UA labs will be improved through improved learning interface allowing more student options and transition from introductory to advanced level CFD template. Hopefully such improvements will increase student agreement. Final versions of TM will be disseminated by FLUENT.

Approach followed for integration of CFD into undergraduate fluid mechanics courses and laboratories should also be useful for integration of simulation technologies for other disciplines into their respective curriculums.

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Author Biographies

FRED STERN is a professor of mechanical engineering with 19 years experience in teaching undergraduate and graduate courses in the mechanical engineering curriculum. Research interests are modeling, CFD code development, towing tank experiments, and uncertainty analysis all in support development simulation based design for ship hydrodynamics.

TAO XING received his Ph.D. in Mechanical Engineering from Purdue University in 2002. He is a Postdoctoral Associate at the hydraulic laboratory at University of Iowa, working with Dr. Stern.

DONALD B. YARBROUGH, Ph.D. in Educational Psychology for the University of Georgia, 1982, is Director of the Center for Evaluation and Assessment and an associate professor of Educational Measurement and Evaluation in the University of Iowa College of Education. His most recent research focuses on program evaluation methodology and the use of standards in student evaluation in higher education.

MARIAN MUSTE received his Ph.D. in Civil and Environmental Engineering from The University of Iowa in 1995. Currently, he is a Research Engineer with IIHR – Hydroscience & Engineering and Adjunct Assistant Professor. He oversees the Fluids Mechanics Laboratory of the College of Engineering where he applies his research expertise in experimental methods and measurement techniques.

ALRIC ROTHMAYER is a professor of aerospace engineering and engineering mechanics with 17 years experience in teaching undergraduate and graduate courses in aerospace engineering. His research interests include viscous flow, computational fluid dynamics, asymptotic methods and boundary layer theory, and aircraft icing.

GANESH RAJAGOPALAN is a professor of aerospace engineering with twenty years of experience in teaching. He has developed a number of undergraduate courses with emphasis on integrating experimental techniques with theory. Dr. Rajagopalan's research emphasis has centered on computationally efficient techniques to study the flow field and operational characteristics of rotating machines such as helicopter rotors, wind turbines, propellers and ducted fans.

RAJESH BHASKARAN is Director of the Swanson Engineering Simulation Program at Cornell University. He is leading efforts in the Mechanical and Aerospace Engineering Department to integrate modern computational tools into the curriculum.

SONYA T. SMITH is an Associate Professor in the Department of Mechanical Engineering at Howard University. She obtained her Ph.D. in Mechanical and Aerospace Engineering from The University of Virginia in Charlottesville, VA in 1995. Dr. Smith has established an active research program in her field of theoretical and computational fluid dynamics and has made contributions in the areas of Aeroacoustics, Vortex-Wake Aircraft Encounters, Simulation of Wake Vortex Dynamics, and Rotorcraft Icing Severity and Detection.