AC 2011-990: REVISED AERODYNAMICS CURRICULUM AND INSTRUCTION FOR IMPROVED STUDENT OUTCOMES

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Revised Aerodynamics Curriculum and Instruction for Improved Student Outcomes

Abstract

This paper describes the implementation of a first course in aerodynamics, revised in both content and methodology, as part of a revamping of the junior-year aeronautics curriculum at Arizona State University, a very large, public institution. The curriculum revision is supported by NASA's *E.2 Innovation in Aeronautics Instruction*. Curriculum modifications include incorporating computational and visualization software into both lecture and homework assignments. In addition, a discovery approach is taken to presentation of key concepts in which students independently investigate aerodynamic behavior of airfoils and wings using the developed software tools. The intended effect of the revisions is to improve students' motivation and ability to persist in the course and in the program. In order to assess their motivation to learn the material and confidence in their ability to do so, students taking the traditional version of the course (Fall 2008) and revised version (Fall 2009 and Fall 2010) were surveyed regarding their perceived ability to achieve course outcomes and to succeed in the course. Analysis of survey data, along with course grades, shows mixed results. The course intervention appears to have improved students' confidence in their ability to master the course outcomes, but it has done little or nothing to improve their perceptions regarding their ability to succeed in achieving a satisfactory grade in the course. The most significant finding indicates that students' self-perception of their ability to master course material and to succeed in the class was virtually uncorrelated with their actual success in the class for students taking the traditional version of the course. In contrast, by the fall of 2010, there is a strong correlation between students' self-perception of their abilities and their performance in the class.

Introduction

Initially, motivation for revising the junior-level aerodynamics course stemmed from the need for preparing aerospace engineers to use state-of-the-art tools in aerodynamic analysis. Current practice in the industry relies almost exclusively on computational methods for design and analysis of wings and bodies. Rarely, if ever, are the classical methods such as thin-airfoil theory or lifting-line theory or even vortex lattice and panel methods still used. It was felt, therefore, that spending excessive time teaching students about potential flow and classical potential solutions was outdated – the probability that graduates would use or even see source, doublet or vortex potentials at any time after conclusion of their aerodynamics course was considered very low. Instead, it was theorized, emphasis should be placed on the important concepts of aerodynamics and modern tools for evaluating them rather than on the specifics of deriving the simplified theory.

Additional motivation arose from previous studies conducted at Arizona State University, which demonstrated that aerospace engineering students reported significantly lower confidence in their

ability to succeed in and lower perceived usefulness of their junior-level courses as compared with their freshman and sophomore courses[1]. This finding suggests that as the difficulty of the curriculum increases, students may find themselves questioning their choice of career path and thus losing interest in or motivation for persisting within the aerospace engineering curriculum.

The aim of the course revision, then, is to modernize both the content and the approach to teaching and learning that content. The original hypothesis stated that a more contemporary approach would stimulate students' interest in learning course material since they would view the content as more useful to them in their future careers. Prior studies have concluded that conventional teaching methods in university engineering courses undermine students' motivation to persist in pursuing an engineering career[2-4].

The first course in aerodynamics is taught during the first semester of the junior year and is scheduled for three hours of lecture and two hours of laboratory each week. Students have taken a first course in thermofluids as a prerequisite. The course is required for all students in the aeronautics concentration of the aerospace engineering major. Most of the students in the astronautics concentration also take the course along with a few students from other engineering majors.

The new version of the course was constructed using several philosophical changes from the previous course delivery:

1. Utilize flow-simulation software (*Overflow2*[5]), including a post-processing visualization package (*FieldView*[6]), in both lecture and homework assignments.
2. Use "just-in-time" approach to integrate laboratory, homework assignments and lecture so that students investigate specific concepts on their own just before being introduced to the mathematical analysis describing those concepts.
3. Remove substantial classical content, such as potential flow solutions, in favor of introducing numerical simulation.

The most significant change to the course was the homework assignments, which require students to perform numerical simulations and to utilize the results to postulate fundamental aerodynamic concepts such as the slope of the lift curve, the variation of induced drag with wing span, *etc*. Students discover these concepts on their own before they derive the simple theories (thin-airfoil, lifting-line, boundary-layer, *etc*.) that predict them.

Course Software Development

For the fall semester of 2009, it was proposed to develop the courseware using the FieldView visualization software along with a commercially available CFD package. This would ensure availability, though not necessarily affordability, of the necessary course tools. FieldView provides a comprehensive, state-of-the-art and relatively easy to use visualization tool. Though its interface is not entirely intuitive, students had little difficulty learning to use its features. The

software is available for both Windows and Linux environments, so it can be used on the common platforms that students routinely use.

Because it was already in use at the university and both graduate students and faculty had some experience using it, Cobalt was chosen as the default computational package[7]. It turned out, however, that the most problematic aspect of the course package was not the visualization tool nor the specific CFD package, but the grid generation. Since a major objective of the course reorganization was to allow students to independently investigate the effects of various airfoil and wing geometries so that they could postulate effects on aerodynamic behavior, they had to have a means to perform numerical studies for many configurations. Even simple changes in airfoil geometry, however, require the generation of a completely new mesh. Since students taking a first aerodynamics course are not required or expected to have anything other than very basic-level coding experience, they are not equipped to handle a typical grid-generation tool. These tools, which tend to require fairly sophisticated tweaking in order to generate successful grids, are not very accessible for beginners, and their use is more likely to scare students away from computational simulation rather than generate enthusiasm for it.

Because of the difficulties with automation of the grid generation routine, it was determined that, at least initially, the students should be provided with already-computed data sets rather than have them generate the aerodynamic data themselves. Students could then import the data into FieldView for study and manipulation, which they did over several homework assignments during the semester. This approach did not allow student to do independent investigation of airfoil or wing characteristics, but it did give them opportunities to utilize modern techniques and to study numerically generated results.

As will be discussed below, the approach did appear to positively affect the students' learning, but it was felt that it would be preferable to provide tools that would allow students to generate their own data. Therefore, during the summer of 2010, an effort was made to develop additional software for students to use in the following semester. A primary goal for the new homework tool was that it should be easy to use for inexperienced students yet allow them to independently investigate the effects of airfoil shape and operating conditions. (Partly because of complexity, but also because of computing requirements, the current tool is restricted to two-dimensional analysis.)

The current version of the course tool consists of a front-end Graphical User Interface, written in MATLAB, that students use to specify airfoil geometry and operating conditions, such as angle of attack, Mach number, Reynolds number, *etc*. The user can specify either a standard NACA 4 or 5-digit series airfoil or a set of *x-z* surface points. The MATLAB code then generates the airfoil geometry and distributes an initial set of computational points on the surface. In addition, the code creates an input file to be used by the numerical simulation routine. Figure 1 shows the user interface that students encounter when opening the MATLAB script. Once the airfoil and

its operating conditions are entered, the airfoil shape and the grid appear in the figure box on the right side of the graphic.
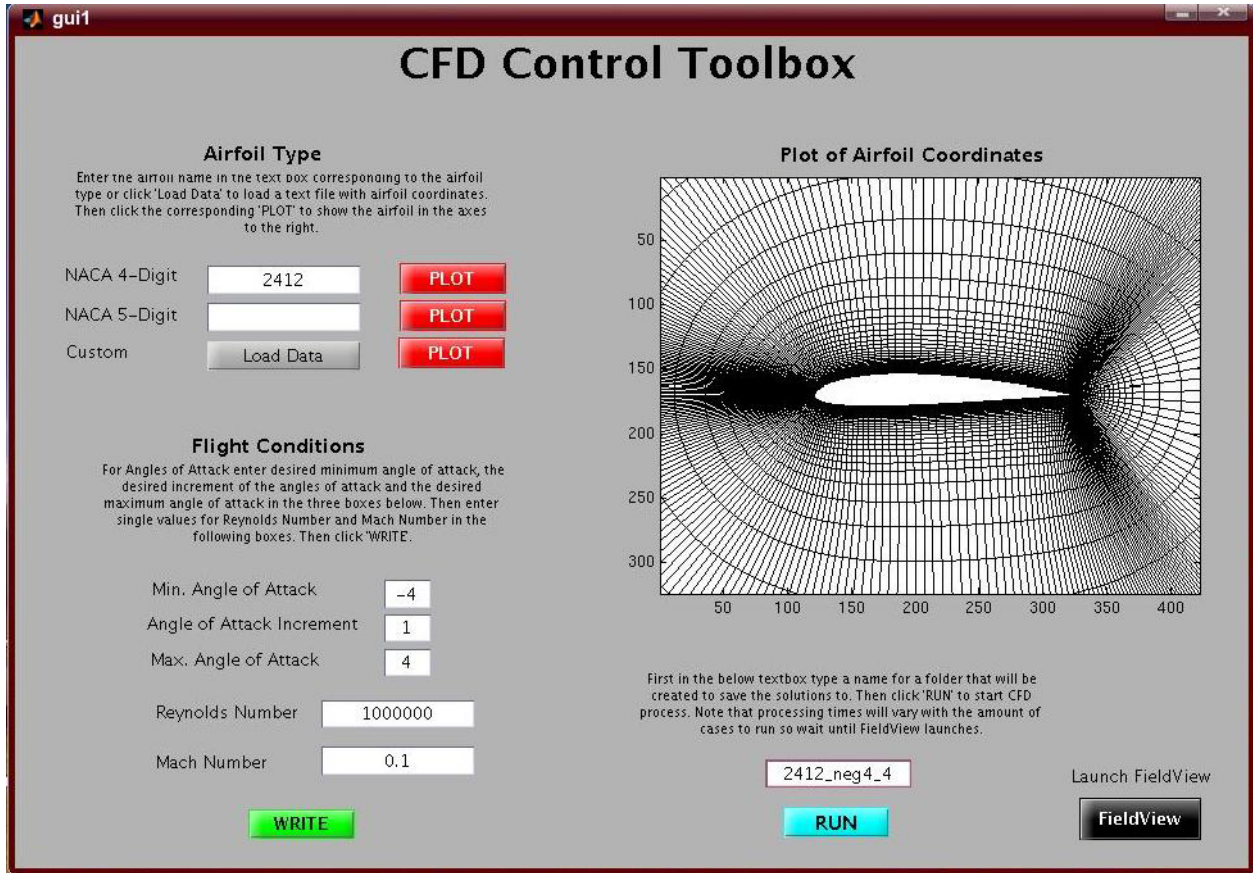

Figure 1. MATLAB-based graphical user interface for controlling CFD tool.

When the user clicks on "PLOT" (to the right of the airfoil specification box), this action executes a *bash* script which generates the distribution of points on the airfoil surface, generates an extruded 3-D wing, creates an O-type grid topological structured grid surface and then executes HYPGEN[8,9] to create a volumetric grid suitable for use by the OVERFLOW2 code. A FieldView FVX script then executes which loads the grid and creates an image of the grid. The grid image is then loaded by the GUI and displayed to the user. When the user clicks on "WRITE" (after specifying the airfoil operating conditions) the GUI creates the FORTRAN namelist files for the OVERFLOW2 code and sets up the *bash* script for the angle-of-attack sweep calculations. Finally, the user inputs a name for a run directory, which declares and creates a directory on a local storage device upon which all the CFD data will be stored. Upon clicking "RUN", another *bash* script is executed, which calls the OVERFLOW *bash* script *overrun* for each of the various angle of attack cases requested by the user. Figure 2 shows the general work flow from MATLAB GUI to FieldView window.
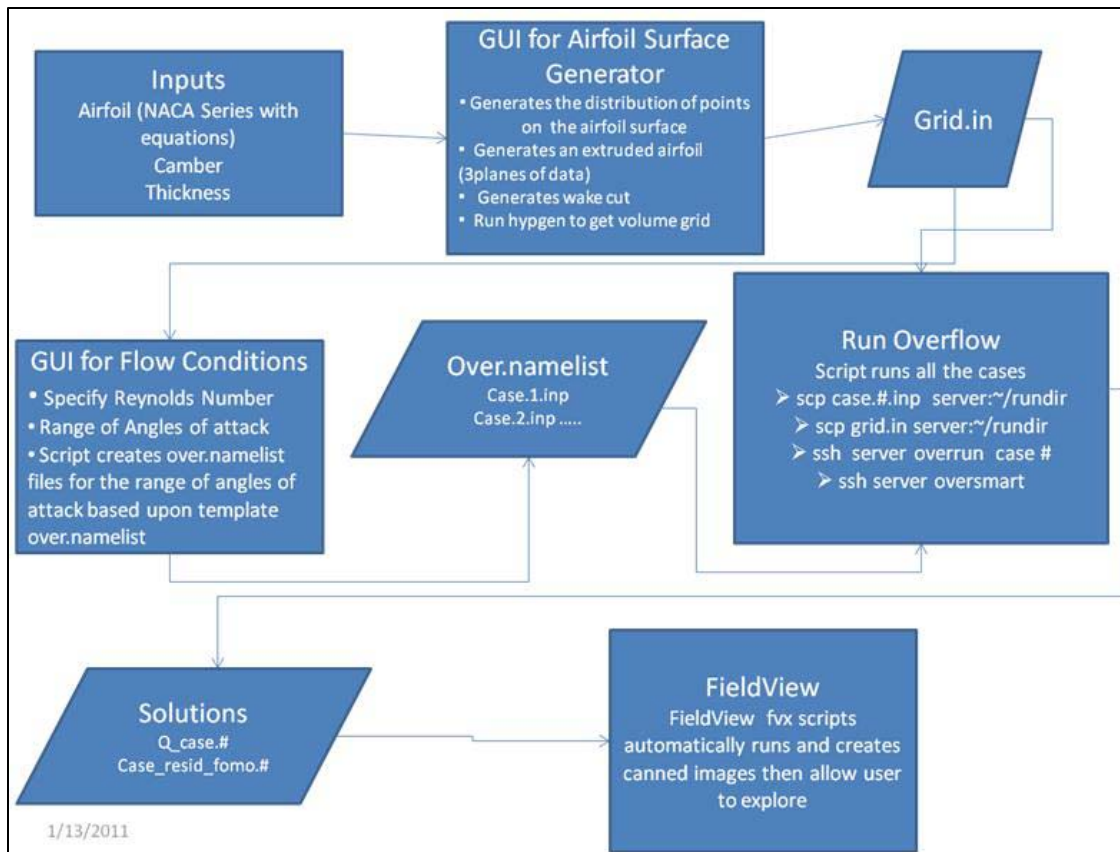
Figure 2. Airfoil analysis tool workflow. (Credit: E. P. N. Duqué)

From the user perspective, the grid generation and the computations are automated. Once calculations have been completed, the resulting geometrical and computed data are loaded into FieldView, which opens automatically in a new window. Figure 3 shows the FieldView setup that students see once the prescribed calculations have finished. The primary view shows dimensionless velocity contours (Mach number), and the insert shows upper and lower surface pressure coefficient distributions. The selected initial views are useful but are not necessarily optimized – FieldView allows for many display options, and an alternative visualization of the data may be preferred depending on the objective of the particular homework exercise. Regardless of the initial view, the students are able to fairly easily manipulate the data to visualize virtually any directly computed or derived field variable.

Overall, the software package consisting of MATLAB GUI, grid generation routine, Overflow2 computational fluid dynamics code and the FieldView visualization provided a readily usable and powerful tool for use in the course. Particular advantages of this combination include:

1. Since students are introduced to MATLAB early in their academic careers, they are familiar with the primary interface and can run the program with no difficulty.
2. Overflow is a public-domain code and is therefore available free of charge (though, see disadvantages below for drawbacks to using Overflow).

3. FieldView provides extensive visualization and analysis capabilities. Students learn the software quickly with very little instruction. The online manuals and tutorials are easy to follow.
4. Since the software is seamless and easy to use, students use it in other courses (such as capstone design) and for extracurricular activities (such as the AIAA Design/Build/Fly project).
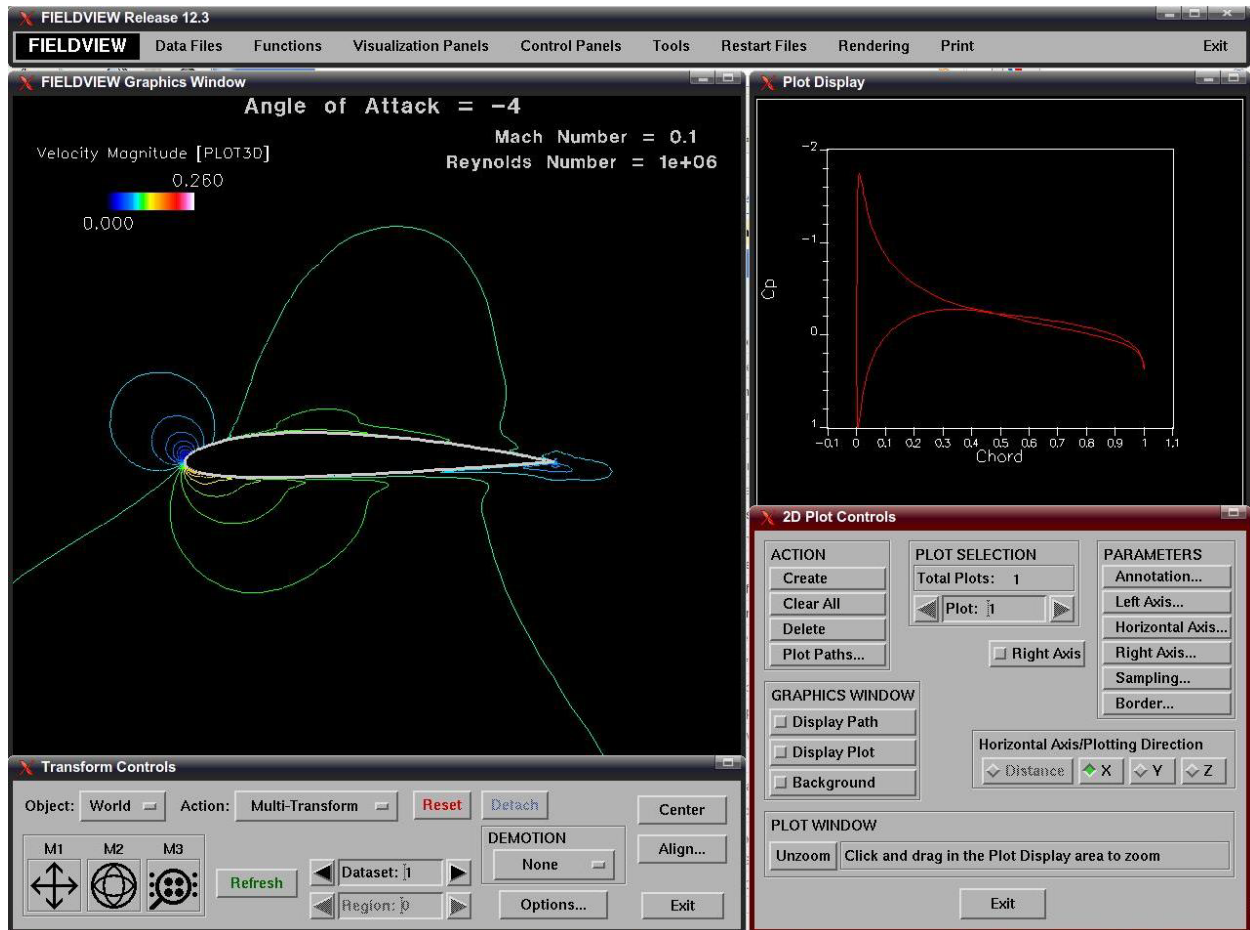

Figure 3. FieldView window upon completion of Overflow calculation.

Despite its apparent success, the package does have certain disadvantages. These include:

1. The Overflow source code is ITAR restricted and thus not universally available. The package that was installed on student-accessible machines consisted only of the executable Overflow code (with permission from NASA) so that the source could not be accidentally read by any users. The executable code is located in an area accessible only by the system administrator.
2. The Overflow code does not run in the Windows environment. Student workstations had to be converted to Linux for the package to be installed. Though in general it is possible to configure PC's as dual-boot machines, the particular machines available do not have

the sufficient capability for both Linux and Windows operating systems. This does limit these machines for use in other courses or applications.

3. FieldView is expensive and available only through an annual license. Despite extensive and eager support from Intelligent Light, the continuing cost of FieldView licenses could prohibit future use and development of the software package.

Implementing the Course

As discussed above, the project objectives include not only incorporating numerical simulation and modern analysis into the teaching of Aerodynamics, but also restructuring the teaching and learning approach to one that is more discovery-oriented. The initial intent was to use FieldView to do extensive in-class demonstrations illustrating various aerodynamic concepts. However, for reasons including purely logistical ones, in-class use of the software was found to be cumbersome in many cases and seemingly not as helpful in demonstrating concepts as was first imagined. (One of the major problems encountered was an incompatibility between Linux and the classroom projection system.) Thus, the software was used only occasionally for classroom demonstration, but it was integrated extensively into the homework assignments throughout the semester.

A typical homework assignment is outlined in the box below. Upon completion of this assignment, students are expected to predict the lift-curve slope for an airfoil and the effect of camber on the lift curve. Up to this point, the classroom discussion has centered on definition of lift and drag, integrating surface distributions of pressure and stress to calculate forces on an airfoil and the physical origin of pressure and stress on the airfoil surface (*i.e.*, what causes pressure to vary on a body in a flow field?). In addition, the students have been introduced to the Navier-Stokes equations – in a previous course, they have encountered the conservation principles, and some class time is taken to illustrate the system of equations and associated unknown values for which the CFD code is actually solving. So up to this point, the class presentation has centered on the concepts of aerodynamic forces and how they arise; it is by completing the homework that the students are introduced to how the forces vary according to body geometry and operating conditions. It is only after students have discovered that the value of the lift-curve slope is 2π, or thereabout, that the class discussion turns to linearization of the governing equations and the simple result from thin-airfoil theory.

Note that the students are not only expected to use the developed courseware, but they also must export the pressure (and, later, skin friction) data from FieldView to MATLAB and generate their own code to calculate forces and moments on the airfoils. This exercise gives students experience and confidence in their own ability to create computer code, and the calculations are reflected in the c_ℓ vs. α and c_d vs. α plots they create.

Figure 4. Sample homework assignment (Homework Assignment #3).

Students complete six assignments throughout the semester:

1. Integrating pressure and stress to get forces on an airfoil.
2. Forces on a NACA 0012 and a NACA 2412 airfoil.
3. Lift and drag as a function of angle of attack for cambered and uncambered airfoils.
4. The effect of airfoil thickness. Comparison with thin-airfoil theory.
5. The Oswald efficiency factor and three-dimensional lift curve.
6. Skin friction and pressure drag as a function of angle of attack.

The assignments require considerable effort in computing, reporting and reflecting on results. Several also require problem solving using thin-airfoil theory, lifting-line theory or boundary-layer results. It is expected that students produce a formal written document for each assignment. (Note that for assignment 5, students are provided with a vortex-lattice code in order to investigate finite-wing effects. Because of reasons outlined above, including lack of computational power, the CFD tool was used only for two-dimensional airfoil analysis.)

Other graded work products in the class include weekly quizzes, three midterm exams and a final exam. Quizzes are designed to test conceptual knowledge and to ensure students maintain currency with the classroom presentation. Exams emphasize problem solving. These are particularly important for monitoring students' ability to utilize standard aerodynamic models (lifting-line, thin-airfoil, boundary-layer) since the homework does not drill them in conventional techniques as was the case in previous offerings of the course. The course also has a weekly laboratory. The lab reports make up 25% of the course grade. (A future improvement to the course will involve more closely integrating the lab activities with the classroom presentation and the homework, thus completing the integration of analysis, computation and experiment.)

Evaluation

Students were recruited from the Aerodynamics courses in three fall semesters: 2008, 2009, and 2010. Fall 2008 (conventional offering) served as the comparison semester. There were 57, 53, and 58 students who completed the class, and 24, 41, and 44 students who participated in the surveys, respectively. Self-reported scales were administered at the beginning, the middle, and the end of each semester. The surveys used in this evaluation were well- established scales that have generated valid and reliable responses from students in post-secondary engineering contexts[10]. Students received a monetary incentive of five dollars for each survey response. Students' course grades were obtained from the instructor and/or the registrar of the university.

Two key foci of the intervention were to support both students' motivation for learning aerodynamics and confidence in their ability to do so. An accepted method for measuring students' motivation for learning is to assess their self-efficacy beliefs through questionnaires[11]. The scales used in this study include:

1. *Motivated Strategies for Learning Questionnaire*. The MSLQ[12] is an established scale utilized to evaluate students' motivation behaviors and their use of different study strategies. Example items from this subscale are, "I am confident I can do an excellent job on the assignments and tests in XXX course". "I'm confident I can understand the basic concepts taught in XXX class," and "I expect to do well in XXX class." The students responded on a Likert-type scale ranging from 1 *(not at all true of me)* to 7 *(very true of me)*.

2. *Engineering Self-Efficacy Survey (ENGSE).* Developed by Yasar[13, 14] and adapted for use in this study, this scale follows the recommendations of Bandura[11] for constructing task-specific measures of self-efficacy. Items examined students' confidence in their ability to perform the specific course outcomes and to solve problems within the aerodynamics course. There are a total of eleven items. Example items from this scale are, "I am confident in my ability to apply lifting-line solutions to solve for pressure, lift, and drag on wings," "I am confident in my ability to describe how airfoil characteristics affect the aerodynamic performance of the

airfoil," and "I am confident in my ability use post-processing software (Fieldview) to analyze airfoils and wings using computed aerodynamic data." The students responded on a Likert-type scale ranging from 0% (*not at all*) to 100% (*completely certain*).

A 3×2 analysis of variance was first conducted to evaluate the effect of two factors on students' engineering self-efficacy (ENGSE): (1) *Year*, a between-subject factor with three levels (2008: students taught by traditional instruction; 2009 and 2010: students taught using alternative mode), and (2) *Time*, a within-subject factor with two levels (at the beginning and at the end of each class). The dependent variable was the averaged self-reported ENGSE rating of 1 to 11. Figure 5 shows results of the analysis. They show a significant Year main effect, $F (2, 106) = 11.37$, $p < .01$, partial $\eta^2 = .18$, a significant Time main effect, $F (1, 106) = 95.18$, $p < .01$, partial $\eta^2 = .47$, and a significant interaction between Year and Time, $F (2, 106) = 5.65$, $p < .01$, partial $\eta^2 = .10$.

A one-way ANOVA and follow-up post hoc comparisons using the Dunnett's C test were conducted to follow any year-to-year significance of the difference in ENGSE between beginning and end of the semester. Results show that the effective change in ENGSE in 2010 was significantly higher than that of 2008, indicating that the curriculum revision indeed had some effect on student confidence.
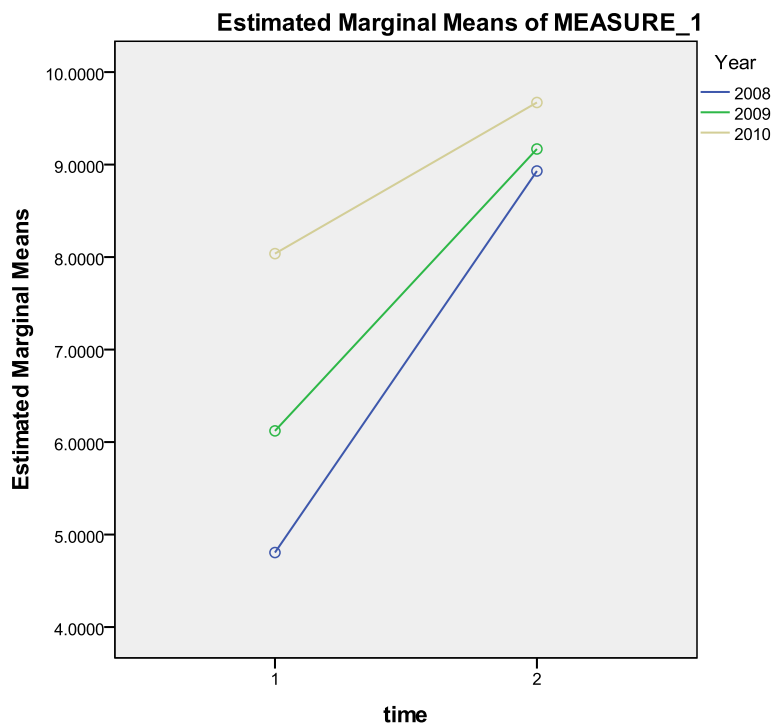

Figure 5: Mean Engineering Self-Efficacy score variation from beginning of course (Time 1) to the end of the course (Time 2)

A 3×2 analysis of variance was conducted to evaluate the effect of *Year* and *Time* on students' expected course success (MSLQ). The dependent variable was the averaged self-reported MSLQ rating of 1 to 6. As illustrated in Figure 6, the results indicate a non-significant Year main effect, $F(2, 106) = 2.52$, $p = .09$, partial $\eta^2 = .05$, a significant Time main effect, $F(1, 106) = 45.06$, $p < .01$, partial $\eta^2 = .30$, and a non-significant interaction between Year and Time, $F(2, 106) = 1.62$, $p < .20$. Unexpectedly, students' beginning of the semester average MSLQ (5.56) was significantly higher than their end of the semester MSLQ (4.90).
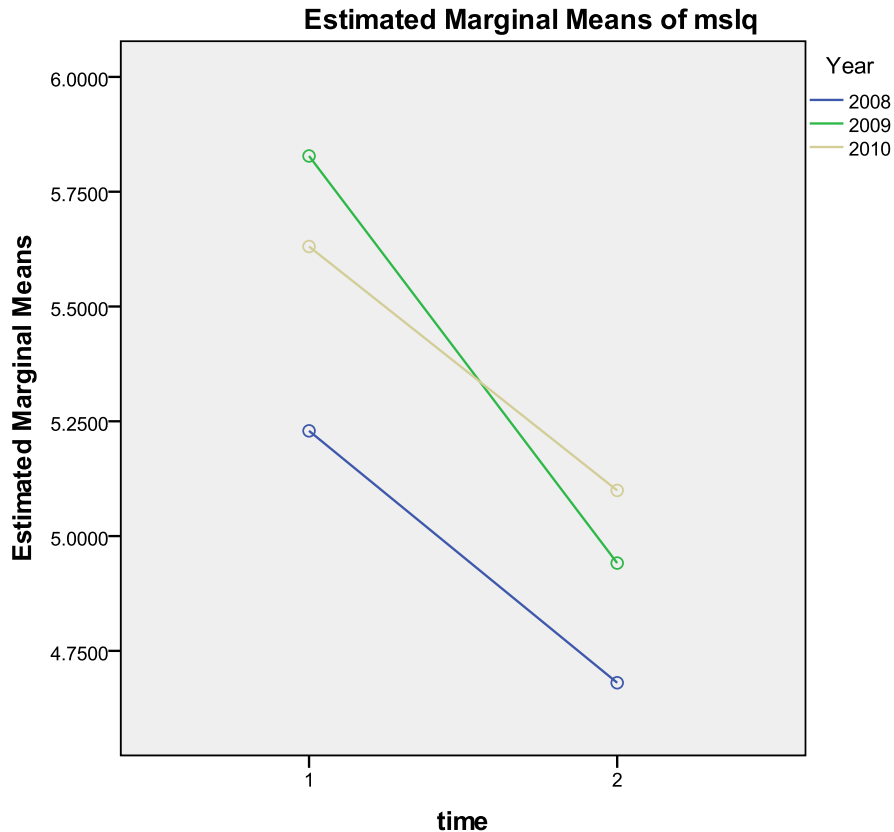

Estimated Marginal Means of mslq

Figure 6: Mean Engineering Strategies for Learning Questionnaire score variation from beginning of course (Time 1) to the end of the course (Time 2)

To further examine students' expectations for their success in the course (MSLQ) and their estimation of their ability to achieve the course outcomes (ENGSE), bivariate correlations between students' end-of-semester beliefs and their final course grades were conducted (see Table 1). The results show that expectation for success and actual success were not correlated during the first year, and that confidence in ability to master course material and actual course success were not correlated during the first two years. However, during the third year, both student expectation and confidence were strongly correlated with their actual success in the course.

Table 1: Relationship between course grade and MSLQ; course grade and ENGSE for each semester.

Year	MSLQ	ENGSE	N
2008	R=.23; p=.24	R=.04; p=.82	29
2009	R=.42; p=.006	R=.07; p=.67	43
2010	R=.39; p=.007	R=.30; p=.04	47

Conclusions

The paper describes the development of a software package utilizing state-of-the-art CFD and flow visualization tools. The package, along with a revised approach to presenting course material, was incorporated into a junior-year aerodynamics course. Students utilized the software package to independently investigate the aerodynamic characteristics of airfoils; in addition, the software was used upon occasion within class periods to introduce the course and illustrate various flow phenomena. Students appear to enjoy using the software, and they continue to use it in follow-on classes and for extracurricular projects.

The reason for developing a new approach to teaching aerodynamics and including visualization software was to support student motivation for learning the content and to improve students' confidence in their ability to learn the content. Student surveys and grades were used to assess the changes in students' beliefs across three semesters of instruction. The results were mixed. The study examined two aspects of student self-efficacy 1) their confidence in their ability to accomplish each course outcome and 2) their confidence in successfully completing the class. Student's self-efficacy for completing the course outcomes improved in all three semesters; students in the 2010 semester had the highest self-efficacy of any of the three years. Students were less confident about their ability to do well on assignments and tests. Students were more confident during the 2010 semester, but in all semesters they finished the class feeling less confident about their performance than when they started.

These findings indicate a separation between students' confidence in their skills in aerodynamics and their skills as students in the aerodynamics course. The curriculum intervention does seem to be "on the right track" as students' belief in their ability to do well in the course did start higher during the intervention semesters and did not decline as significantly as during the traditionally taught semester. Additional modifications, however, maybe needed to align the students' perceptions of their ability to succeed in the course with their actual ability.

That students' final grade in the class is not significantly related to either their expectations of how well they do in the class or their belief in their ability to achieve the course outcomes during the baseline semester provides additional support for the conclusion that students' perception of their abilities and course performance were not well aligned. This misalignment was improved in the first semester the course was changed; students' expectations for how well they would perform was positively and significantly related to their final course grade. The students'

confidence in their ability to achieve the outcomes, however, was not related to their final grade. Further improvement in this alignment occurred in the final semester of the intervention; both students' expectation for how well they would do in the course and their confidence in their ability to achieve the outcomes in the class are positively and significantly related to their final grade in the course. This indicates that students' self-beliefs and the assessment in the class were better calibrated in the most recent semester that the course was taught.

It is not yet known how the course modification may affect students' overall success in the major. Future plans include analysis of the correlation between participation in the modified junior-year curriculum and student persistence and graduation rate. In the meantime, additional revisions to the aerodynamics course will include a stronger alignment of the laboratory experience with the class presentation and homework assignments. It is hoped that this will provide a greater sense of the utility of the course material and thus further improve student learning and persistence in the course.

Acknowledgements

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