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Abstract Aerodynamics curriculum in undergraduate engineering has reached a critical juncture forcing the need for change in the traditional, largely theoretical curriculum and lecturer/listener pedagogy. The role of aerodynamics in aerospace engineering, while still important, is no longer the dominant driver in aircraft design. Furthermore, industry, government, and academia --- the likely employers of aerospace graduates --- desire a workforce which is the more holistic and systems-thinking as opposed to the highly specialized, research-oriented engineer of past generations. Simultaneously, modern aerodynamics has been revolutionized by Computational Fluid Dynamics (CFD) while our undergraduate curriculum has largely neglected its use. Advances in the pedagogy of technical learning have also occurred which offer the potential to greatly improve the effectiveness of our teaching. In this paper, we report on two years of effort to re-engineer our aerodynamics education at the Massachusetts Institute of Technology. In particular, we discuss (1) the use of a Lockheed Martin aerodynamic design project to provide educational motivation and authentic learning experiences, (2) the application of active learning to improve student classroom engagement and student-faculty interaction, and (3) the integration of theoretical, experimental, and computational techniques into a modern aerodynamics curriculum.

Introduction

In recent years, engineering curriculum reform has received serious attention from industry, government, and academic groups as the need for change in engineering education has become a well-recognized problem. The department of Aeronautics and Astronautics at the Massachusetts Institute of Technology has recently begun a strategic effort to reform its curriculum with three specific goals:

- To educate students to master a deep working knowledge of the technical fundamentals
- To educate engineers to lead in the creation and operation of new products and systems
- To educate researchers to understand the importance and strategic value of their work

To achieve these goals, the department proposed to set its curriculum in the context of the life-cycle of an engineering system. Thus, the Conception, Design, Implementation, and Operation (CDIO) of engineering systems would form the backdrop against which the department's curriculum would be set. The department also proposed to pursue a parallel initiative in pedagogical approaches to improve the faculty's ability to guide student learning. This initiative was spurred by advances in pedagogy which have occurred in the sciences and the arts but have made relatively minor impact in engineering.

Within aerodynamics, the need for re-engineering the traditional curriculum is critical. Industry, government, and (to some extent) academia has seen a significant shift away from engineering science and highly specialized research-oriented personnel toward product development and systems-thinking personnel. While technical expertise in aerodynamics is required, it plays a less critical role in the design of aircraft than in previous generations. In addition to these influences, aerodynamics has been revolutionized by the development and maturation of computational methods. These factors cast significant doubt that a traditional aerodynamics curriculum with its largely theoretical approach remains the most effective education for the next generation of aerospace engineers. We believe that change is in order.

During the past two years, we have been re-engineering our undergraduate aerodynamics course (M.I.T. course

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number 16.100). In this paper, we will discuss three aspects of our reform work, specifically:

1. The use of a Lockheed Martin aerodynamic design project to provide educational motivation and authentic learning experiences,
2. The application of active learning to improve student classroom engagement and shorten student-faculty feedback, and,
3. The integration of theoretical, experimental, and computational techniques into a modern aerodynamics curriculum.

Course Objectives

16.100 *Aerodynamics* is one of a set of upperclass subjects which undergraduates have the option of using to complete their degree requirements. The course is offered once a year in the fall semester and generally has an enrollment of around 30 students. Prior to this course, students have some exposure to basic fluid dynamics including conservation principles, potential flows, and some incompressible aerodynamics including thin airfoil theory and lifting line.

As a first and important step in the re-engineering of this course, we developed a set of course objectives. We have continually used these objectives to guide our decisions on every aspect of the course. Specifically, students that successfully complete this course will be able to:

1. Formulate and apply aerodynamic models to predict the forces on and performance of realistic three-dimensional configurations;
2. Assess the applicability of aerodynamic models to predict the forces on and performance of realistic three-dimensional configurations and estimate the errors resulting from their application;
3. Design and execute a computational and experimental aerodynamic analysis together with members of a team.

While the specific aerodynamic models could vary from semester-to-semester, in general, they will likely include: 2-D and 3-D potential flows (incompressible to supersonic); boundary layer methods including the effects of transition and turbulence; 2-D and 3-D Euler and Navier-Stokes computations.

For the first and second objectives, we specifically emphasize the prediction of not only aerodynamic forces but also aircraft performance. We believe that connecting the prediction of aerodynamic forces to aircraft performance (i.e. to the system performance) is critical to the development of engineering judgment in aerodynamics. Throughout the course, the students are often required to perform a sensitivity analysis to quantify how aircraft performance estimates (e.g. range, take-off distance, etc) are impacted by errors or uncertainty in aerodynamic predictions (e.g. drag coefficient, lift coefficient, etc). In addition, these objectives require the analysis of realistic three-dimensional configurations. The application of aerodynamics to reasonably complex configurations is an important learning experience as students must confront the approximations and uncertainties which are an inescapable part of all but the simplest engineering designs.

The third objective requires a team-based experience performing a computational and experimental aerodynamic analysis. The purpose of this experience is to expose the students to the respective roles of experiments, computations, and theory in a typical aerodynamic analysis. The use of teams is largely a result of the intended complexity of the aerodynamic analysis which would be too difficult for a single individual to complete. Furthermore, when teams are working effectively, learning can be enhanced by team member interactions.

Problem-based Learning

Interest in problem-based learning (PBL) arose in higher education in response to criticisms that programs in professional areas, *e.g.*, medicine, engineering, failed to equip graduates with the problem-solving skills required for a lifetime of learning (Wilkerson & Gijselaers, 1996). Problem-based learning has now become a widespread teaching method in disciplines where students must learn to apply knowledge not just acquire it.

The main goal of problem-based learning is to provide students with opportunities to apply knowledge, not just acquire it. PBL focuses on problem formulation as well as problem solving. It seeks to simulate real-world engineering research and development. Barrows (1996) describes the main features of PBL in this way:

- Learning is student centered, *i.e.,* students make choices about how and what they want to learn.
- Learning occurs in small student groups and promotes collaborative learning.
- Teachers are facilitators or guides or coaches.
- Problems form the organizing focus and stimulus for learning.
- Problems are a vehicle for the development of authentic problem-solving skills.

- New information is acquired through self-directed learning.

Problem-based learning promotes students' active engagement with learning. Learning becomes an act of discovery as students examine the problem, research its background, analyze possible solutions, develop a proposal, and produce a final result (Delisle, 1997). Not only is this style of learning more interesting and engaging for students, it also develops a greater understanding of the material since students find the information for themselves and then actively use the information and their skills to complete the project.

Problem-based learning is attractive not only from its apparent strengths in improving student learning, but also, problem- or project-based learning aligns with our departmental CDIO initiative to make the engineering product lift-cycle the context for engineering education. Typically, aerodynamics and other advanced engineering topics are taught with a significant focus on theory but little opportunity to apply theory especially to problems that approach the complexity faced in the design of modern aircraft. As a result, the decision was made to utilize a case study from either industry or government to motivate the entire course. A specific goal of the case study, as reflected in the course objectives, was for the students to design and perform an aerodynamic analysis involving both computational and experimental methods.

<u>Lockheed Martin Case Study</u>

During the summer of 1999, we contacted several industry and government representatives requesting a case study which could serve as the semester-long theme of our aerodynamics course later that fall. Lockheed Martin Aeronautics Company (LMAC) proposed a case study based on a typical re-design scenario encountered in the military aircraft industry. Specifically, the student teams were to develop aerodynamic models of an F-16-like wing-body geometry at several critical operating conditions and then use these aerodynamic models in a wing design trade study. The interaction with LMAC was facilitated by the third co-author, Michael Love with additional support from LMAC co-workers, Dennis Finley and Antonio de la Garza. The case study (with some modifications) has been the basis for both the Fall 1999 and Fall 2000 semesters.

This case study includes flight regimes from low subsonic to supersonic speeds including some at high angles of attack. Furthermore, in order to validate the aerodynamic models, experimental data for the various flight conditions is required; although some of the necessary experimental data was available from LMAC, the project also required wind tunnel testing to be performed. For the modeling portion of the case study, the specific requirements were:

1. Establish analytic-modeling requirements for reliable prediction of lift and drag on the baseline configuration under the critical operating conditions given below. Assess the error in the aerodynamic predictions relative to the experimental data and assess the sensitivity of the predictions to analytical modeling parameters.
2. Handbook/textbook methods should be used to incorporate the aerodynamic data into calculation of range, specific power (ability to sustain turn rate), and take-off distance. Assess the uncertainty in the prediction of these performance metrics resulting from the uncertainty/variability of the aerodynamic prediction errors established in Task 1.
3. Lift curves and drag polars are to be developed to characterize the configuration at the critical operating conditions.

The critical operating conditions to be addressed were:

1. Take-off (sea level)
2. Mach 0.6 (10K ft) Maneuver Point (4g's)
3. Mach 0.9 (10K ft) Cruise Point (1g)
4. Mach 1.2 (10K ft) Supersonic Dash Point (1g)

Additional details are contained in Appendix A.

After completion of the modeling portion of the project in early November, the last third of the semester focused on performing a trade study using the validated aerodynamic models. During Fall 2000, the teams considered the impact of leading and trailing flaps and variations in wing sweep and span on the aircraft take-off, cruise, and dash performance.

<u>Discussion</u>

The past two years using problem-based learning has generally been very positive. The following is a discussion of some aspects of our experience:

- A common difficulty with traditional approaches to engineering courses is that students perceive they are learning material 'just-in-case' they may need it later in their careers. In the proposed problem-based approach, a significant portion of the course curriculum focuses on the knowledge required to address the case study (the daily schedule for the course is given in Appendix B). Also, the natural motivation to successfully complete the project (we have found) often creates a situation in which students are pulling the information from the course staff as opposed to the more typical pushing of knowledge on the students.

- Another important aspect of the case study was to tie the aerodynamic analyses taught in this course back to the system, i.e. the F-16, and its performance. This concept of system-motivated analysis is critical because it forces the students to continually evaluate their engineering analysis relative to system performance metrics. For example, the second project requirement is to propagate aerodynamic performance predictions (such as lift and drag coefficients) and their uncertainties through to system level performance metrics. This focus naturally leads students to the concept of sensitivity analysis with the result that students quickly learn to balance the *perceived* desire for accuracy in aerodynamic performance estimates with the *actual* need for accurate system performance estimates.

- In our implementation of the case study, the student teams remain the same for the entire semester. Furthermore, approximately 50% of the final grade is based on the team project. As a result, over the length of the semester, most teams experience some amount of frustration and stress. Thus, in addition to providing technical guidance, the teaching staff must also closely monitor the health of the teams and help mitigate problems as early as possible.

- Based upon our Fall 1999 experience, we increased the use of scheduled class time for the purpose of team project work sessions. This guaranteed that teams would all have the ability to meet at a time when all students were available; also, this allowed the teaching staff the opportunity to closely interact with the teams. Thus, for the Fall 2000, we designated a significant (almost half) of the class time as potential team work sessions (see Appendix B for more details). The drawback to this strategy is that it decreases the amount of time that can be spent discussing new material.

- During the past two years, the students have consistently found this team project to be an effective pedagogical approach. Appendix C contains the results from the most recent end-of-semester student evaluations of the effectiveness of the 16.100 pedagogy. As can be clearly seen, the team project is the second-highest-rated item behind only the textbook (Anderson).

Active Learning

Most engineering courses are taught with a traditional 'chalk talk' or lecture approach complimented with some combination of homework, labs, and exams. Unfortunately, traditional lectures are well known to be an inefficient approach to teaching. A different approach with a wide variety of implementations is active learning. Unlike lectures, active learning seeks to engage the students with the material in class. At its most basic level, active learning can be used simply to break the monotony of a lecture; however, active learning can be much more than entertainment. When implemented properly, active learning can decrease feedback time between faculty and students, improve higher order thinking, encourage self-driven learning, clarify common misconceptions, etc (Crouch & Mazur, in press; Felder & Brent, 1996; Hake, 1998; Heller & Hollobaugh, 1992; Heller, Keith, & Anderson, 1992; Johnson & Johnson, 1989, 1996; and Meltzer & Manivannan, 1996). However, most uses of active learning have been carried out in science education at the elementary, secondary, and undergraduate levels, while only a few applications (Mourtos, 1997) have been made to engineering education.

During the Fall 1999 semester, we began using a peer instruction approach, similar to that developed for physics by Mazur (1997) at Harvard University. In this approach, conceptual questions are given to students in class with time for individual thought and reflection. After a check to see how well the students have understood the question, small group discussions are held (if needed) in which the student groups attempt to answer the question. Afterwards, the instructor clarifies any misconceptions and leads the students in further exploration of the concept or topic. Crouch & Mazur (in press) have written an excellent overview of both the implementation and the results of peer instruction based on their eight years of experience with the approach.

<u>Discussion</u>

Implementation of peer instruction in an advanced undergraduate course such as *Aerodynamics* is unfortunately not trivial. However, in the past two years, we have made progress towards an effective implementation. In the following, we highlight some of the major issues we have encountered:

- Student preparation for class is a critical element to the success of active learning. Without preparation, students cannot effectively participate in conceptual questions unless the questions are quite simple. Also, preparation is critical to reduce the class time spent introducing material prior to the use of a conceptual question. In our implementation of peer instruction, we give weekly pre-class reading and homework assignments. The homework consists of 3-4 questions and focuses on the quantitative application of aerodynamics. The goal is for the students to be comfortable with the material without requiring conceptual mastery of the topics. From the Fall 2000 student evaluation data (see Appendix C), the pre-class reading and homework assignments were quite positively rated by the students (half the class felt the assignments were very effective in encouraging learning).

- In addition to the weekly homework assignments, we also include a short self-assessment. We specifically ask the students to rate their understanding on a 5-point scale of the relevant topics from the assignment. Also, we ask the students what aspect of the reading or homework was most confusing or most interesting. The self-assessments are administered on a Web-based system. The main advantage of the Web interface is the speed with which the faculty can assess the most difficult aspects of the reading. We used this information to help direct our preparation for class including identifying which concepts to focus on during subsequent in-class peer instruction.

- A major advantage of active learning is that it can significantly reduce the time delay between students and faculty. In typical classes, faculty are not fully aware of the level of student understanding until the related homework or exam is completed and graded. Unfortunately, this time delay can often be weeks. Thus, by the time at which faculty recognize a learning deficiency, it may be difficult or impossible to rectify the problem. However, the in-class conceptual tests, the pre-class homework, and the weekly self-assessments give the faculty a set of nearly immediate feedback mechanisms on the class understanding.

- While the Fall 2000 students did find the in-class concept questions effective, the average ranking was a relatively low, 2.36. A similar low rank of 2.14 was also given to the lectures. Since the student rating of the faculty teaching was extremely high (this data is not shown), we believe these good but lower relative ratings to be a reflection on the difficulty of constructing appropriate concept questions. The problem stems from the need to reduce often complicated theoretical aerodynamics to a key conceptual question which can be answered in a few minutes. On the positive side, this difficult task does improve as the base of good concept questions grows (albeit slowly) with each semester.

Integration of Theory, Experiment and Computation

Our past aerodynamics curriculum had a significant focus on theoretical aerodynamics with some limited exposure to experimental and computational aerodynamics. However, as suggested by Murman & Rizzi (2000), "today's aerodynamics engineer needs to be fluent in modern CFD methods and tools, and must know how to utilize them in conjunction with theory and experiment for aerodynamic analysis and design." While this seems an undeniable reality, the difficult problem is how best to integrate CFD into the mainstream aerospace curriculum.

We envision that the large majority of aerospace engineers will only have experience with results of a CFD calculation, some engineers will be end-users of CFD, and a very small fraction will be involved in some aspect of CFD development. Thus, our general philosophy for integration of CFD into our undergraduate course was that the underlying aerodynamic approximations embodied by a computational tool must be well understood by a modern aerodynamicist, however, the details of the numerical methods are less important. Thus, we expect students to understand that a three-dimensional, compressible Euler calculation can model shock waves but, being inviscid, is not appropriate when viscous effects might be critical. Furthermore, we expect students to understand that a vortex lattice method, in addition to being inviscid, is a linear method which is only valid for thin bodies and small angles of attack. By contrast, we do not expect students to understand what a second-difference artificial dissipation operator is, or how a Roe approximate Riemann solver differs from Van Leer flux-vector splitting.

As can be observed from the class schedule in Appendix B, we discuss a variety of computational methods including: 2-D panel methods, 2-D coupled integral boundary layer and panel methods, vortex lattice methods, and 3-D Euler solvers. Although we anticipate the use of 3-D Navier-Stokes simulations in the near future, to date we have not pursued this level of complexity. Furthermore, during the course of the semester (largely through the case study), the students actually apply all of these methods.

We have found that the application of these methods can provide many important learning experiences. For example, in the F-16 case study, students quickly learn that at low speeds, a vortex lattice method which runs in seconds is much more effective than a 3-D Euler solver which requires hours to complete. Or, when applying two-dimensional coupled boundary-panel methods to the airfoils of the F-16, the students experience first hand the sudden leading edge separation of thin airfoils at low angles of attack (and, almost as suddenly, realize the futility of using 2-D simulations for a low aspect ratio, highly swept wing).

For this course, we use the following software:

- Xfoil: 2-D coupled boundary layer-panel method written by Mark Drela
- MSES: 2-D coupled boundary layer-Euler method written by Mark Drela
- AVL: vortex lattice method written by Mark Drela
- FELISA: 3-D unstructured grid Euler solver written by Jaime Peraire

For ease during the development of the new curriculum, we have used software developed at M.I.T. Except for the vortex lattice solver, all of the codes are ‘industrial strength’ and have been used in a wide variety of applications from academia to government to industry. We recently have begun investigating the use of commercial CFD software for classroom purposes and anticipate utilizing this type of package in the next year or two.

We believe that all modern aerodynamics engineers should have a good grasp of the coupled but different roles of theory, experiment, and computation in the aircraft analysis and design. Thus, we devote a significant amount of class time to this issue, and, in fact, the case study requires that the student teams develop validated aerodynamic models for all critical operating conditions. In this process, students learn that neither CFD nor experiments are capable of providing reliable predictions for all applications, and understanding both the agreement or lack thereof between CFD and experiment is a crucial role for an aerodynamicist.

To compliment the CFD coverage, we also devote a portion of the class to wind tunnel testing. Perhaps more importantly, as part of the case study, low speed wind tunnel tests must be conducted on a $1/9^{th}$ scale model of the Lockheed wing-body geometry in the M.I.T. Wright Brothers’ Wind Tunnel. As observed from the student course evaluations, the wind tunnel testing is one of the most effective (and exciting) portions of the course. The student teams perform force balance calibrations, develop their own testing plan, run the tunnel experiment, and post-process the data (including correcting for various tunnel effects). This data is then used for validation and calibration of a vortex lattice-based aerodynamic model with a skin-friction drag estimate. At higher flight speeds, the experimental data was available from previous Lockheed Martin tests.

Conclusions

While the impact of curricular and, in particular, pedagogical changes can often be difficult to quantify, we can without hesitation state that the students from the past two years have a significantly different balance of skills than students from the tradition curriculum taught previously. These differences include:

- Experience developing, validating, and applying aerodynamics models for the analysis and design of realistic, three-dimensional configurations;
- An understanding of the impact of uncertainty and variability on aerodynamic predictions and the resultant impact on aircraft system performance estimates;
- A working knowledge of Computational Fluid Dynamics;
- A working knowledge of the complimentary roles of theory, experiment, and computations in aerodynamic analysis and design.

In the coming years, we will further refine our aerodynamics curriculum including new case studies for problem-based learning, a continued evolution of our peer instruction approach, and integration of commercial-strength CFD software and Navier-Stokes simulations.

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Appendix A - Fall 2000 Team Project
F-16 Modeling Analysis

Background: An increased size wing is desired for the F-16 fighter aircraft. The wing must allow for improvements in all aspects of performance: low speed handling qualities, transonic maneuver and cruise, and supersonic dash. A baseline configuration (called the VAT) has been derived through vehicle synthesis studies. The design of the production wing will largely rely on analytic models. Throughout the design process, parametric sensitivity studies will be performed with the analytic models to determine potential modifications to the current wing that will improve performance for the next design cycle. In particular, parametric studies will be required to determine the effect of aspect ratio, area, and sweep on the wing performance at critical conditions. Thus, analytic models must be identified or developed, correlated, and calibrated to minimize the uncertainty of the performance estimates later in the design cycle.

Available data, models, tools:

1. In anticipation of the need to correlate and calibrate analytic models, some initial transonic and supersonic experimental data have been acquired for a baseline trapezoidal wing on a body of revolution defined by the following parameters:

Wing Area	338.29 ft^2
Aspect Ratio	3.28
Taper Ratio	0.2142
Leading-edge Sweep	40 degrees
Semi-span	199.86 inches
Airfoil	64A003.5 @ BL 41.5 (Wing Root)
	64A004 @ Wing Tip
Twist	0 degrees

An electronic definition of this model and the wind tunnel data will be made available.

2. A 1/9 scale model of the VAT is available for testing in the MIT Wright Brothers Wind Tunnel (WBWT).

3. A variety of analytical/computational tools covering sub/tran/supersonic speeds will be made available.

4. The following information may be assumed for the nominal aircraft:

Empty weight	14,700 lb
Fuel weight	7,000 lb
Specific fuel consumption (intermediate)	0.74 lb (fuel)/lb-hr
Specific fuel consumption (max take off)	2.05 lb (fuel)/lb-hr
Max Thrust @ 10K ft	18,000 lb
Max take off thrust	24,000 lb

Requirements: The Preliminary Design Methods Group at Lockheed Martin Aeronautics Company has requested the following tasks to be completed by November 3, 2000:

1. Establish analytic-modeling requirements for reliable prediction of lift and drag on the baseline configuration under the critical operating conditions given below. Assess the uncertainty in the

aerodynamic predictions relative to the experimental data. If appropriate, assess the sensitivity of the predictions to analytical modeling parameters.

2. Handbook/textbook methods should be used to incorporate the aerodynamic data into calculation of the relevant performance metric. Assess the sensitivity in the prediction of these performance metrics resulting from the uncertainty/variability of the aerodynamic prediction errors established in Task 1.

3. Lift curves and drag polars plots are to be developed to characterize the configuration at the critical operating conditions.

Critical Performance Metrics & Operating Conditions:

1. Estimate the take-off velocity at sea level conditions. Assume that the angle of attack is limited to a maximum of 15 degrees to avoid the tail striking the ground.

2. Specific excess power estimate for Mach 0.6 (10K ft) maneuver point (4g)

3. Radius of action estimate for Mach 0.9 (10K ft) cruise point (1g)

4. Dash time estimate from Mach 0.9 (10K ft) to Mach 1.2 (10K ft) (1g)

Appendix B
Daily Schedule - Fall 2000

Wk 1	Sep 6-8	Short Week – Subject Set-up
Wed	Lecture	Course overview Case study presentation by Lockheed Martin
Thu	Electronic	Computational Fluid Dynamics demo
Fri	Electronic	Computational Fluid Dynamics demo
Wk 2	Sep 11-15	Aircraft Performance & Sensitivity Analysis
Mon	Electronic	Initial team meeting for LMTAS project **Homework #1 due by 4 PM**
Tue	Lecture	Discussion: aircraft performance & sensitivity analysis
Wed	Lecture	Discussion: aircraft performance & sensitivity analysis
Thu	Lecture	Discussion: aircraft performance & sensitivity analysis
Fri	Lecture	Discussion: aircraft performance & sensitivity analysis
Wk 3	Sep 18-22	Viscous Flow & Boundary Layer Basics
Mon	Electronic	Project team work session **Homework #2 due by 4 PM**
Tue	Lecture	Discussion: viscous flow & boundary layer basics
Wed	Lecture	Discussion: viscous flow & boundary layer basics
Thu	Lecture	Discussion: viscous flow & boundary layer basics
Fri	Lecture	Discussion: viscous flow & boundary layer basics
Wk 4	Sep 25-29	Boundary Layers & Vortex Lattice Methods
Mon	Holiday	No class
Tue	Electronic	Project team work session **Homework #3 due by 4 PM**
Wed	Lecture	Discussion: boundary layers & vortex lattice methods
Thu	Lecture	Discussion: boundary layers & vortex lattice methods
Fri	Lecture	Discussion: boundary layers & vortex lattice methods
Wk 5	Oct 2-6	Vortex Lattice Methods & Low Aspect Ratio Aerodynamics
Mon	Electronic	Project team work session **Homework #4 due by 4 PM**
Tue	Electronic	Discussion and/or Project team work session (as needed)
Wed	Electronic	Discussion and/or Project team work session (as needed)
Thu	Electronic	Discussion and/or Project team work session (as needed)
Fri	Electronic	Discussion and/or Project team work session (as needed) **Interim Modeling Report for Lockheed Case Study due by 4 PM**

Wk 6	Oct 9-13	Wind Tunnel Testing
Mon	Holiday	No class
Tue	Holiday	No class
Wed	Electronic	Project team work session **Homework #5 due by 4 PM** Tunnel tests (outside of class)
Thu	Lecture	Discussion: wind tunnel testing Tunnel tests (outside of class)
Fri	Lecture	Discussion: wind tunnel testing Tunnel tests (outside of class)
Wk 7	Oct 16-20	Compressible Flow & CFD
Mon	Electronic	Project team work session **Homework #6 due by 4 PM**
Tue	Electronic	Discussion: compressible flow & CFD
Wed	Electronic	Discussion: compressible flow & CFD
Thu	Electronic	Discussion: compressible flow & CFD
Fri	Electronic	Discussion: compressible flow & CFD
Wk 8	Oct 23-27	More Compressible Flow
Mon	Electronic	Project team work session **Homework #7 due by 4 PM**
Tue	Lecture	Discussion: compressible flow
Wed	Lecture	Discussion: compressible flow
Thu	Lecture	Discussion: compressible flow
Fri	Lecture	Discussion: compressible flow
Wk 9	Oct 30-Nov 3	Extra week for project help, clarifications, etc.
Mon	Electronic	Project team work session
Tue	Electronic	Project team work session
Wed	Electronic	Project team work session
Thu	Electronic	Project team work session
Fri	Electronic	Project team work session **Final Modeling Report for Lockheed Case Study due by 4 PM**
Wk 10	Nov 6-10	Design Trade Project & Boundary Layer Methods
Mon	Lecture	Introduction to Design Trade Project **Homework #8 due by 4 PM**
Tue	Lecture	Discussion: boundary layer methods
Wed	Lecture	Discussion: boundary layer methods
Thu	Lecture	Discussion: boundary layer methods
Fri	Holiday	No Class

Wk 11	Nov 13-17	Panel Methods & Airfoil Aerodynamics
Mon	Electronic	Project team work session **Homework #9 due by 4 PM**
Tue	Electronic	Discussion: panel methods & airfoil aerodynamics
Wed	Electronic	Discussion: panel methods & airfoil aerodynamics
Thu	Electronic	Discussion: panel methods & airfoil aerodynamics
Fri	Electronic	Discussion: panel methods & airfoil aerodynamics
Wk 12	Nov 20-22	Airfoil Aerodynamics
Mon	Electronic	Discussion: airfoil aerodynamics
Tue	Electronic	Project team work session
Wed	Electronic	Project team work session
Thu	Holiday	No Class
Fri	Holiday	No Class
Wk 13	Nov 27-Dec 1	High Aspect Ratio Aerodynamics
Mon	Electronic	Project team work session **Homework #10 due by 4 PM**
Tue	Lecture	Discussion: high aspect ratio aerodynamics
Wed	Lecture	Discussion: high aspect ratio aerodynamics
Thu	Lecture	Discussion: high aspect ratio aerodynamics
Fri	Lecture	Discussion: high aspect ratio aerodynamics
Wk 14	Dec 4-8	Extra week for project help, clarifications, etc.
Mon	Electronic	Project team work session
Tue	Electronic	Project team work session
Wed	Electronic	Project team work session
Thu	Electronic	Project team work session
Fri	Electronic	Project team work session **Design Report for Lockheed Case Study due by 4 PM**
Wk 15	Dec 11-13	Review week
Mon	Lecture	Discussion: review as needed
Tue	Lecture	Discussion: review as needed
Wed	Lecture	Discussion: review as needed

Appendix C
Fall 2000 Student Evaluations

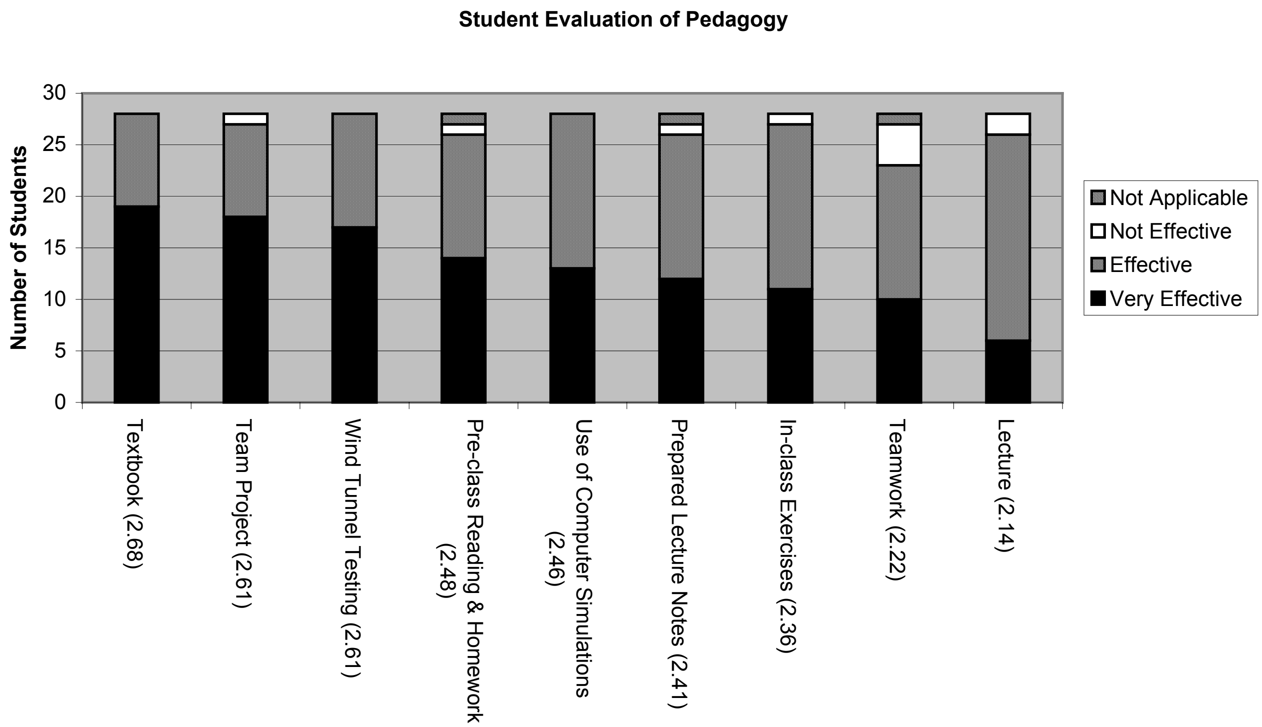

Table 1: Student evaluation of pedagogy for Fall 2000 (average rating shown in parentheses)