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Applied Aerodynamics Education: Developments and Opportunities

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APPLIED AERODYNAMICS EDUCATION: DEVELOPMENTS AND OPPORTUNITIES

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Abstract

Many practicing engineers feel that recent graduates aren't ready to go to work after graduating. They feel that new graduates don't really understand "engineering." Boeing has produced a list of desirable attributes intended to guide engineering educators in improving the "product," as well as starting an industry-university-government group to address engineering education. In this paper we review the issues from our current perspective and suggest that the Boeing list of attributes can be connected to the broader issue of cognitive development, and Perry's model in particular. We then describe the modern, mainly web-based, methods we are using to attempt to improve aerodynamics education. Using Java and other approaches, students can investigate aerodynamic concepts without becoming distracted by programming issues.

Introduction

We have been actively involved in engineering education for nearly a decade. Within the broad context of engineering education, this paper addresses our understanding of the educational challenges facing engineering educators based on our classroom and industrial experience, our classroom and laboratory instructional efforts in aerodynamics, and new opportunities available for improved education afforded us by the developed of the web and other advanced technology such as Mathematica. We also consider the possibilities for education-industry interaction

Many engineers in industry have expressed concern about the education of engineering students. Perhaps the most famous (infamous?) assessment is attributed to Lee Nicolai:[1] "We educate great scientists but lousy engineers." John McMasters from Boeing has also written about Boeing's perception of the problems with the current system.[2,3] In general, for the last ten years we have heard that the products of the schools are "not really ready" to go to work.

After some investigation, it appears that the problem expressed by industry has more to do with the development of an engineering mentality than the technical preparation of the students, although there are also some concerns in that regard. Previously, we surveyed the members of the AIAA Applied Aerodynamics TC from government and industry to try to understand the issues a little more specifically.[4] The survey was intended to address the technical issues of what specific topics needed more emphasis in aerodynamics classes, but the respondents chose to emphasize the general engineering attitude, and the work ethic in general, with equal vigor. Apparently, this problem still exists.

In an attempt to address the general engineering issues, at Virginia Tech case studies were used in an Applied Computational Aerodynamics course.[5] This worked reasonably well, pushing the students to use their own judgment in applying computational methods. The students found the requirement to locate information, work in teams, and develop a basis for making decisions very difficult. Apparently, these were all new aspects of their education. One can only speculate as to whether the importance given to student teaching evaluations keeps teachers from introducing this engineering emphasis in courses. Certainly the grading is much more subjective and the faculty work load is much higher. Students are extremely uncomfortable with this approach, and that might explain the poor teaching evaluations typical of using this approach with large groups (as with everything else, small classes can use these approaches much better). We have described related efforts associated with design.[6,7,8] and multidisciplinary design optimization education elsewhere.[9]

The first section of the paper describes our experience in trying to prepare students for careers in engineering, with a review of our perception of "the problem" in developing the "engineering attitude" from

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students that are still developing maturity. We will try to understand where we've been and where we might go. Next, we examine the opportunities afforded education by the emergence of the internet and related technology. We will then discuss recent developments in web/Java oriented instruction in foundation courses, and describe our work in senior/graduate level elective courses oriented toward both additional aerodynamics education and the development of an engineering approach. Finally, the new opportunities for industry-academia interaction are discussed.

Where we've been

To consider ways to produce better applied aerodynamicists in the future, we need to consider past experience. Two items stand out. Ira Abbott, of Abbott & von Doenhoff fame, was the after dinner speaker at a NASA Conference on Advanced Technology Airfoil Research at Langley in 1978. He talked about the way new engineers broke-in in the early days of the NACA. He said that they plotted wind tunnel data for about two years before they were allowed to do anything else. This afforded a postgraduate opportunity to learn on the job that probably doesn't exist today. The first author plotted data at McDonnell and later for the Army at Edwards AFB during co-op and summer jobs. The opportunity to learn more aerodynamics, especially in the wind tunnel with veteran aerodynamicists is probably rare today.

A second anecdote involves my colleague, Adjunct Professor Nathan Kirschbaum. Nathan graduated from MIT in 1951, and spent his entire career in the aerospace business, primarily in aircraft configuration design. When he considers the range and depth of knowledge we expect from our students in design class he shakes his head in wonderment. He is amazed at our expectations compared to his day. The oft-used analogy is that we make them drink from a firehose.

There is no doubt that we are putting a lot in the curriculum. At the same time, many universities are demanding more courses be taken in a core curriculum which includes the humanities and the social sciences. And in many cases, state legislatures are putting limits on the number of hours required to graduate. The result is that the requirements placed on the students are already significant and no more credit hours are going to be added to the graduation requirements. In response to industry, most courses include projects, frequently team-based. This adds a major burden to the student workload. Thus, although industry would like to see us add a lot more, it's unrealistic for a four year degree. However, it's a natural for a five year degree, with the final product being an MS or MEng.

Where we are now

There is no doubt that the educational system will undergo significant change. Remarkably, many engineering colleges are ignoring the inevitable. Although they claim to be embracing change, it's essentially superficial. The faculty, for the most part with no exposure to engineering practice, are simply not capable of the needed change. Since the current faculty are responsible for hiring the new faculty, no mechanism for change exists. Several powerful recent discussions of the situation seem to have been completely ignored. *The Monster Under the Bed* by Davis and Botkin[10] addresses education in general. Two other important engineering specific examinations of education were written by Ferguson[11,12] and Goldberg.[13] Both of these deserve attention, but appear not to have received any.

There are however some positive developments toward making the Master's Degree the primary engineering degree. MIT has embarked on this approach, and descriptions of the program in Aeronautics and Astronautics[14] and Electrical Engineering[15] are available. Other schools are also following this trend.[16] Virginia Tech has introduced a somewhat novel program that combines the students from five participating departments in a program that requires two common core courses and department-specific courses to allow the student to major in a particular degree.[17]

There is one other significant development. As an outgrowth of Boeing interest in engineering education, a Industry University Government Roundtable on Engineering Education (IUGREE) has been meeting for the last several years. This organization demonstrates a real commitment to engineering education by the top management of the major companies in the aerospace business. The results of this activity have not been felt at the working level by educators, although individual company efforts such as summer programs to expose faculty to current practice have been ongoing for several years. The work of this group will be interesting to follow.

The educational dilemma — Perry's theory of development of college students

The problem of getting students to develop the attitude toward aerodynamic analysis and design that industry seems to want has a direct connection to the problem of development of college students identified by Perry.[18] The educational theory community has been aware of Perry's model of development for many years. It's part of an education major's basic coursework. However, few engineers and engineering educators are aware of this theory.

The first author learned about it when he attended the National Effective Teaching Institute, which has been given by Rich Felder and Jim Stiles regularly in association with the annual ASEE Conference. After learning of the theory, details were found in the book by Wankat and Oreovicz,[19] Mason read the chapter in this book on Perry's model and was astounded to see a perfect description of his own students. Having come from industry, his views on engineering education were closely aligned to the assessments by Nicolai and McMasters. It turned out that engineering students have simply not been pushed to develop to the level of cognitive development required to satisfy the request for an "engineering attitude."

Table 1, which the first author constructed in 1993 to help digest the theory, shows the problem, and warrants study. The characteristics that Nicolai identified first in his list include the ability "to shift back and forth between left and right brained activities", "perform trade studies to make the compromises necessary for achieving a balanced design", "be able to develop selection criteria considering all relevant issues". Examining the table, we can see that the characteristics Nicolai is looking for most likely correspond to a stage 5 or above on the development chart. According to Wankat and Orevicz, a new engineering graduate is unlikely to be at a stage 5 or above at graduation. As a design teacher, Mason often approaches the group as if they were at stage 5. This is a serious problem, students at stage 2 or 3 can't even understand the discussion of issues at a stage 5 level. However, stage 5 has an special problem. In this stage you start to question your life choices, spouse, career, etc. It's best to move quickly to a level of commitment.

The problem is that most engineers, as well as students, want a "right" answer to a problem. Even though they are exposed to open-ended problem solving, students have a hard time actually working comfortably in this environment. Typically, they don't like the subjective grading associated with this type of academic work. In general, the teachers don't like working with students in this manner either. Everybody wants straightforward problems with unambiguous answers. It matters little that this model, the primary paradigm for engineering education, has nothing to do with actual engineering practice. Although the liberal arts courses often attempt to push the students to move further up the development ladder by stressing analysis of multifaceted problems, the personality types attracted to engineering seem not to benefit from these courses. Whether the instruction is inadequate or the students simply unwilling, the benefits of this aspect of the liberal arts courses don't seem to be realized.

No matter how far along the mental development path we are in areas we are familiar with, almost all of us immediately revert to a stage 1 or 2 when faced with an entirely new subject area. We want to know *the* answer, with no concern for the subtleties of the subject.

As currently operated, engineering schools give the students as much information as possible, as efficiently as possible, with little regard for pushing the students to move up the level of the development ladder defined by Perry. There are of course a few exceptions. However, "diving in" and trying to relate to students as seasoned engineers is doomed to failure. Trying to teach students as if they were on stage 4 or 5, when they are actually at 2 or 3, will simply result in frustration for both the students and the instructor.

One study has been published recently that presented the results for engineering students.[20] At the Colorado School of Mines, they predicted that on average, entering freshmen were at a stage of 3.27, while students graduated at a stage of 4.28. This was below their goal of stage 5 for graduates. There was a wide variation in the student achievement. They found that one third of their students were below stage 4 at graduation. They thought that the improvement of one stage on average over four years was a significant achievement.

Industry must understand that they need to complete the development of their engineers, providing a way for their engineers to progress to levels 8 and 9 after they graduate. Viewed from this vantage point, we can all understand the problem and tackle it constructively. In the intensely competitive global market place it would appear critical to achieve a competitive advantage for industry work toward this goal.

Opportunity: Computers and Education

Computers *per se* certainly aren't new for aerospace engineering or aerodynamics education. Sometimes it appears that this a recent development. The first author took a required FORTRAN course in the mid '60s and was given plenty of programming assignments as an undergraduate. Availability of a computer was never a problem, although access was awkward.* The computer certainly played a role in education even then.

However, with the advent of the personal computer and the introduction of graphical interface

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* Today's students haven't seen a computer card and are confused about why old input instruction manuals describe "card numbers."

browsers, and finally, the possibility of platform independent computing through Java, computers can be viewed in an entirely different light. Other key developments include platform independent document dissemination through Adobe's PDF file format and free Acrobat Reader, and spreadsheet and high level tools such as MATLAB and Mathematica which are nearly device independent. Opportunities to improve education have come with this revolution and require careful consideration. A staggering array of possibilities exists, and educators have been introducing educational innovations for some years.

Some examples of applied aerodynamics oriented instructional software include the programs from Desktop Aeronautics by Ilan Kroo of Stanford,[21] originally developed for the Macintosh, work by Kurt Gramoll and co-workers at Georgia Tech,[22] also for the Macintosh, and by Higuchi from Syracuse,[23] again for a Macintosh. The first author jumped-the-gun slightly by developing codes for programmable calculators in the early '80s.[24] This last effort demonstrated the problem of developing programs that were platform specific, and also failed to anticipate the coming revolution in personal computers. We reviewed the general status of aerodynamic program availability for classroom use several years ago.[25] We have a web page extension of that paper with a current assessment, intended for students in aircraft design.[26]

Despite the widespread availability of software, the impact on most engineering education appears to be limited. A study by J.B. Jones of Virginia Tech shows that that we are simply not yet realizing the potential benefits from computer.[27] Before describing our efforts to improve the situation, we will review a couple of issues.

Computation in place of theory?

Our faculty have considered whether to deemphasize the theoretical content of our courses in favor of a more application oriented approach. We concluded that an emphasis on the fundamentals of aerodynamic theory cannot be reduced. The power of computers is such that very large calculations can be made by a single junior engineer. Thus, we need to make sure that the students are provided with the theoretical basis for the computations being carried out. In today's environment the importance of a fundamental understanding of basic fluid mechanics is even more important. Thus the issue becomes how to provide this information. An approach that uses electronic means to aid the student, so that fundamentals can be learned without requiring too much effort not specifically germane to the study is required. This has to done in a way that will move the student along Perry's stages.

Actual "programming" by undergraduates

With the introduction of high-level environments such as spreadsheets, MATLAB and Mathematica, the role of classical programming languages, and the emphasis on students learning them with any degree of proficiency has arisen. It appears that engineers going directly to work with a BS degree may not engage in classical programming. Those that do often say that FORTRAN was not used. Thus, practicing engineers should be aware that while students use existing applications extensively, the emphasis on traditional programming is diminishing rapidly. This is possibly more important for the universities, where graduate students are typically expected to do programming, and their skills in this area are becoming very weak. It appears counterproductive in a content-specific course to have students struggle with programming, when that skill has little to do with the specific course material. This is an example of the problem of trying to separate specific course material from engineering skill in general.

A Solution: Use of Java in foundations courses

Several key courses offered in aerodynamics at Virginia Tech have moved to the web in large part. These include the required undergraduate course in compressible aerodynamics, the required junior year undergraduate lab and the required first year graduate course in theoretical aerodynamics. The purpose is to improve student understanding by enhancing insight into the material. A by-product is reduced cost in terms of textbooks and the ability to refine the material continuously.

Background

As described above, educators have realized the value of computer-based tools for enhancing engineering education for some time. More recently, it has become clear that the capability of the computer to interact with its user, to compute and then display the consequences of that interaction in a dynamic form, provides an avenue for learning that is simply not available in the classroom or textbook. Efforts described above were platform specific, using the Macintosh. Other efforts have been workstation based.

For the most part, the efforts have been local to the course or institution where they were developed. The fundamental problem was that programs were not easily distributed and were not usually compatible with more than one computer operating system. For most educators, translation and distribution of software beyond their own students was simply not worth the effort, especially when the program itself may be short and simple.

The advance of technology now offers a real solution to these problems in the form of the new Java programming language and the World Wide Web. As it has for society in general, the web has also become an essential resource and tool for students and educators. Its strength and popularity arise from the fact that access to information is not machine or location dependent. Anyone running a browser on any machine can access any Web page from anywhere in the world. In effect, the World Wide Web solves the distribution problem (one computer company says “the network is the computer”, it took us a while to understand - we do now). Originally, web pages had a weakness, in that they only offered static access to information. To foster an appreciation of basic engineering principles and to stimulate an interest in pursuing further education in engineering, dynamic interaction is also required. Java solves that problem and allows the user to run programs directly through the web browser. Many Java applets have been developed for this purpose at Virginia Tech. We provide two examples.

The Java applets described here are also available to practicing engineers and industry where they can contribute formally or informally to continuing education and, depending on content, provide simple design or computational tools.

Example #1: Potential Flow

To illustrate how these instructional units work we discuss one Java applet and accompanying HTML documentation. The instructional unit is available over the web at:

http://www.aoe.vt.edu/aoe5104/ifm/ifm.html

Note that a Java capable browser is needed to run the applet itself. This instructional unit is designed to assist the teaching and understanding of two-dimensional ideal flow. The applet is embedded in a series of HTML documents that describe the applet, its educational goals and the subject matter being addressed. Examples are provided as well as the source code.

A screen print showing the actual applet window is illustrated in Fig. 1. The window shows a grid (the rectangular region containing the '+'s) and a graphical user interface containing four text fields labeled 'Strength', 'Angle' 'X' and 'Y', and a pull-down menu with the selections 'Freestream', 'Source', 'Vortex', 'Doublet', 'Source Sheet', 'Vortex Sheet' and 'Draw Streamline'. The fields 'X' and 'Y' show the position of the mouse on the grid, the fields 'Strength' and 'Angle' may be edited to allow the user to enter any numeric value.

The applet simulates a water tunnel in which the student adds any of a variety of elementary flows and then visualizes the net resulting flow by adding dye at specific points (i.e., a Hele Shaw table). The student may add any number of sources, vortices, doublets, source sheets, or vortex sheets. With 'Draw Streamline' selected the computer will draw streamlines starting wherever the student clicks the mouse on the grid.

The applet allows the student to freely experiment with ideal flow, without being tied to its (often cumbersome) algebraic description. It teaches the student about the principle of superposition, about the form of those elementary flows and about the nature of streamlines. It also enables the students to easily visualize and experiment with any basic ideal flow field they may meet in class or their textbook or any other flow they desire.

This applet is platform independent. In terms of file size, the applet and its accompanying HTML documents are small and load rapidly over a modem. It is accessible to anyone in the world with an internet connection.

Example #2: Boundary Layer Calculation

A second, more recent, example demonstrates the use of Java to compute a boundary layer.[28] This applet is one of a number of applets being developed to demonstrate the boundary layer methods described in the book by Schetz.[29] The applet is available at:

http://www.engapplets.vt.edu/

In this case, the student can enter the edge velocity distribution and see the solution. Figure 2 provides an example of the screen. Here, the reader should try it for himself. Paper-based presentation is too far from the actual environment to provide real insight into the environment. Several other schemes are also available. The use of Java in this course is critical to enhancing student understanding. Where it was previously difficult for students to actually compute meaningful solution, it becomes trivial.

Numerous other examples of Java-based online aids to instruction are available from the Virginia Tech AOE web page on web-related teaching materials, located at:

http://www.aoe.vt.edu/aoe/courses/webteach.html

as well as the applets project url given above. Of specific interest are the laboratory manual, several other Java applets, including ones for conformal transformation, and an online version of NACA 1135. In almost all instances, the material is available for anybody, at any location.

This section has provided two examples of the use of Java in instruction. For the most part, we no longer have to worry about students having different computer setups than the one that was used to develop the application.

Other web-based teaching approaches

Building on the foundations established in the required courses, several elective courses are offered to seniors, which are also available for graduate credit. These courses emphasize design and engineering practice. They include courses in computational structural design and optimization, flight control system design, and applied computational aerodynamics and configuration aerodynamics. Essentially, seniors have to take at least one of these courses. For this paper, we will discuss the applied computational aerodynamics and configuration aerodynamics courses, taught alternate years by the first author.

As seniors, we attempt to bring the students along Perry's ladder. Thus, touching on the material discussed in the courses, but requiring more than the basic information presented, the students are assigned term projects.[*] To do this they work in teams of about three or four. Each topic is different, and the students present their assessment of the problem examined in class presentations.

The Applied Computational Aerodynamics course has been described before,[5] and the course notes and various codes are available electronically at:

http://www.aoe.vt.edu/aoe/faculty/Mason_f/
CAtxtTop.html[†]

This is a hybrid document, using an HTML framework to provide PDF files of course notes and to allow students to download source codes for use in the class.

Students are generally assigned one methodology project and one applications project. The methodology project results have generally been disappointing recently. This is because student proficiency in programming has deteriorated as students use MATLAB or spreadsheets rather than FORTRAN in other courses. Typical applications projects could be assessments of existing aircraft or design projects related to the AIAA Undergraduate Team Aircraft Design Competition. These have been described in detail previously.[8] The most interesting assignments are arranged around topics of current interest. The one that generated the most interest was the assignment to assess and pick the YF-22 or YF-23 as the winner of the ATF competition. Amazingly, the assignment due date, picked several months in advance, turned out to be the day the Air Force announced the winner. These types of projects require considerable engineering judgment in addition to the specific course material. Curiously, after these projects were switched to use teams, the quality of the projects deteriorated.

In Configuration Aerodynamics students do one component concept investigation and one case study of an entire configuration. One example of a component investigation is the investigation of how a winglet works. Examples of entire configuration investigations include the Voyager and the B-2. Although we requested that these presentations be made electronically so that they could be put on the web, the students generally copied material from copyrighted sources, so that it would appear to be a copyright violation to post the presentations on the web. An additional component of the class is the use of classic configuration aerodynamics papers, which are discussed in class. The problem with that approach is the bipolar nature of the class. About half the students seem to dominate the discussion, while the other half remain silent, probably not having read the paper.

We have found that using the web makes course administration much easier. Past problems of putting codes on a floppy disk in a computer lab, with the inevitable virus, vanished. Distribution of notes became trivial using PDF files. And email seems to be very effective. The location of the Applied Computational Aerodynamics Course notes was given above. A somewhat different flavor of web use is available for the Configuration Aerodynamics course, which is located at:

http://www.aoe.vt.edu/aoe/faculty/Mason_f/
ConfigAero.html

As a much newer course, not all the material is as well organized. Since these materials are available to anyone, we appreciate comments. We certainly get a lot of feedback about our information sources pages, design class notes and online codes (which include QuickBASIC versions of several of the old calculator programs[24]). All of these web pages can be found from the airplane design course site:

http://www.aoe.vt.edu/aoe/faculty/Mason_f/SD1.html

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[*] The areas to be investigated are not cast specifically in terms of the course material. To me the connection is obvious. However, several students from outside the department taking the course, and not familiar with Mason's approach, have asked if the term project has *anything* to do with the material being covered.

[†] Virtually all the web addresses contained in this paper can be found starting at http://www.aoe.vt.edu/

Curiously, we get more comments on these sites from web surfers outside the university, with a significant percentage from abroad, than the students in our classes. Neither of these classes has progressed to the point of using Java applets. However, the students have used the methods described above, and if appropriate they are available for use. Finally, the students surf the web to locate information on their aerodynamic concepts and configuration case studies. Thus the web is a key part of the course.

A few lessons

Perhaps the key lessons are the impact Java can have on courses, and that web orientation eases course administration. The ease with which information can be upgraded, and the ready acceptance, and even expectation, that the course be essentially "on the web" has changed the way some of us do business.

Platform independence is critical. Even if students all had PCs, the variation in systems from year to year was a constant problem. Changes in compilers given to students each year also caused chaos. It is unfortunate that industry is apparently not ready to maintain a common Java, and platform independence may disappear.

Some of our experiences may be useful to others:

Unintended consequences

One of our first applications of Java in an engineering course was the Compressible Aerodynamics Calculator, at:

http://www.aoe.vt.edu/aoe3114/calc.html.

This program, written in JavaScript, was designed as supplementary material for our compressible aerodynamics course AOE 3114 which most students take in the Spring of their junior year. The course teaches the basics of one-dimensional compressible flow, of shock expansion theory and of the method of characteristics. As such we had made extensive use of NACA 1135 Equations Tables and Charts for Compressible Flow.

The calculator was conceived as a tool for replacing these tables and greatly reducing the drudgery of performing simple compressible-flow calculations. The idea was that with less time spent looking at the numbers the students could spend more time thinking about the aerodynamic principles. To some extent this has happened. The students make regular use of the calculator for homework and other assignments, and the calculator has received some attention from users outside the university, both at educational establishments and in government and industry. However, the calculator has failed to replace the tables completely. In exams and tests the students don't have access to a computer and must still use NACA 1135 (which as a consequence they still have to buy). Being less familiar with the printed tables they are then more likely to make mistakes and this leads to frustration. Universal access raises the possibility that we have introduced this frustration into other aerodynamics classrooms across the nation!

Information Transfer vs. Information Presentation

Our experiences suggest that the world wide web has two quite different educational functions and that it can be important to identify the intended function in preparing WWW material.

Eighteen months ago we made the decision to convert the manual used for our undergraduate laboratory course into an HTML document, with the idealistic objective of constructing a "paperless course". The manual consists of some 250 pages of background material, experiment descriptions and other instructions for students. The electronic version, now available at http://www.aoe.vt.edu/aoe3054, boasts an equivalent volume of web pages. We make it available in every laboratory through a networked computer and web browser.

To our surprise the web version of the manual has not replaced the paper copy. The latter still sells out. Students, it seems, don't like to read material from computer screens any more than their professors. This does not mean the online manual is redundant - far from it. We get many positive comments from students pleased to be able to cut and paste figures and tables from the manual to their lab reports (with appropriate references of course), to print out a second copy of a chapter after the first one was damaged, and who were able to prepare for the lab when out of town without having to carry a heavy book. It seems that the dominant value of the web in this application is the ease with which it allows us to transfer material to students - it is not such a good tool for presentation. This is evidenced by the few JavaScript functions that are spread throughout the otherwise HTML manual. We could have saved some effort here since these are hardly used, the students come across them when reading their printouts!

With the idea of information transfer in mind, in 1997 we added another facet of the web to our laboratory experiments. The networked laboratory computers that used to stand nearly idle, now carry email clients and the Microsoft Office suite of programs. In advance of the lab experiment, students email the lab a copy of a spreadsheet or similar document which they have prepared to receive the results and perform some of the analysis. During the experiment they complete the spreadsheet and then email a copy to all the members (typically 5 or 6) of the laboratory group involved in the experiment, so all can incorporate it first hand into their reports. This program was entirely optional, but almost all students use it - it is simply a much more efficient and accurate way of transferring preparation into the lab, and results out.

All this is not meant to imply that information presentation is not a practical application of the web. Presentation of information can be done very effectively using sequences of HTML screens (see http://www.aoe.vt.edu/aoe3054/manual/stu1/session1 for example) or the many Java and JavaScript programs referenced here and elsewhere. However, it is worth noting that the primary function of these applications is presentation rather than information transfer because none of them are useful if printed out.

Uses of Java and JavaScript Programs.

Amongst the numerous Java and Javascript programs that have been written for engineering education, it seems there are two types - the ‘virtual environment’ and the ‘calculator’ - both have substantial educational potential.

An example of the first type of applet is the Ideal Flow Machine

(http://www.aoe.vt.edu/aoe5104/ifm/ifm.html).

described above. This applet, designed to assist the teaching and understanding of elementary two-dimensional ideal flow, creates an interactive graphical environment aimed at enhancing understanding and interest. It is not designed to produce numerical solutions (although some limited numerical output is available). The major role of this type of applet is the presentation of concepts in a manner not possible on a blackboard or in a textbook. For example in fluid dynamics Java applets can represent fluid motion explicitly and thus make clear the often misunderstood relationships between wave and particle motion, geometry and velocity and the role of the pressure field in controlling flow. Further examples of such applets include the Virtual Shock Tube:

http://www.aoe.vt.edu/aoe3114/shocker/shocker.html

and the Ideal Flow Mapper:

http://www.aoe.vt.edu/aoe5104/mapper/mapper.html.

An example of the calculator type applet is the program ILBLI

http://www.engapplets.vt.edu/fluids/bls,

(figure 2), also mentioned above. This applet is designed expressly for numerical input and output - the user enters as numbers the various parameters needed to define the boundary layer flow (initial boundary layer thickness, pressure gradient parameter, free-stream velocity, viscosity and edge velocity distribution) and the computational domain (starting and ending points, grid spacing etc.). The edge velocity distribution is also input as pairs of numbers into a table - long lists of such number pairs can be cut and pasted from other applications. The user then presses the start button to initiate the calculation, the results of which are plotted real time as the calculation progresses. The plots, however, are only rudimentary and are not mean't to provide any kind of environment to enhance learning, just an immediate feedback on whether the calculation is advancing correctly. The real output of the program is in tables of numbers representing the boundary layer velocity profile at a particular location and the development of the boundary layer parameters along its length. These tables of values may be cut and pasted from the applet into any other applications and, indeed, have been formatted to be Excel compatible.

In this type of applet the student is not the explorer of a new (to them) theoretical concept, but the analyst who has to provide the proper input to, and interpret and analyze the output from, a computational tool that contains no safeguards ensuring that the answers are meaningful or useful. A key part of this program, and its relations is its use of tabular input and output that may be accessed using standard cut/paste/copy operations. This compatibility with the 'clipboard' and thus applications native to the host computer largely overcomes the limitation of JAVA programs not being able to read or write files on the hard disk. It also opens up the possibility of developing a suite of applets that the student can use in combination to investigate the solution to more general problems. For example, we are in the process of developing a panel code applet and an applet to determine transition location given laminar boundary layer parameters as a function of streamwise distance. Given a geometry in the form of a paneling scheme, the panel code will provide edge velocity and coordinates as table output, and these may then be pasted into one of the laminar boudary layer codes. Results from this applet may then be pasted into the transition calculator whose output is used to initialize one of the turbulent boundary layer applets. In addition, one envisions output from the panel method being pasted into a structural analysis applet, or output from the boundary layer applets being pasted into a drag calculator, combined with output from a lifting line theory applet and then pasted into a performance applet. It seems then that the modularity and compatability that these type of calculators offer may go some way into breaking down the artificial barriers that students perceive between the different disciplines in their field - a key step if these students are to become effective designers.

A related development: a digital textbook

The possibility of providing students with a modern aerodynamics text with interactive examples self-contained for use on a PC has been realized with the publication of a digital textbook by Prof. Ilan Kroo of Stanford.[30] In some respects this book is strikingly similar to the approaches adopted at Virginia Tech. The book runs through a browser, making it nearly device independent. The book is quite an accomplishment. It contains an amazing amount of material, including numerous QuickTime movies, some with sound. There are also many interactive computations included. I would suggest this book to anyone, and when I get email asking about a starting place to learn applied aerodynamics we now recommend this book. We also have beginning graduate students interested in applied aerodynamics but without an aerospace engineering background use this book for independent study. More information describing the details can be found at:

http://www.desktopaero.com

Opportunities for Industry

Techniques to allow interaction between students and industry are now available using the internet. Several years ago, John McMasters proposed providing students with a few telephone numbers, so that students could contact experts in industry to contact with questions. It's my impression that this doesn't work too well. A fax might be a little better, but it also doesn't work well. These types of interactions can provide answers to specific questions. But they have limited potential for developing the "attitude" that industry wants. Engineers in industry are too busy, and the students don't really know who to contact or exactly what to ask. The primary place this interaction occurs is in design class. There, a limited number of contacts seems to work. But the number of students benefiting from this interaction is extremely small.

In the applications area, electronic interaction is now possible. Already, newsgroups such as sci.aeronautics provide a useful means of obtaining information. Unfortunately, there is also a large amount of misinformation. A newsgroup run under the sanction of the AIAA or the IUGREE, could filter some of the extraneous information, and provide students with answers to questions. Using a set of email addresses to remind a list of industry volunteers to check the newsgroup, we could expect feedback that would be available to every reader, with a large increase in the student impact. A number of other more advanced interactions are also available. For text-oriented interaction, liberal arts courses are typically more advanced than engineering classes. In many classes, students are required to interact with each other and the whole class. Means to do this are available today, and are inexpensive.

Is Industry Causing a Problem Themselves?

We think we understand the basis for industry concern about engineering education. We have suggested a way to address the situation by telling students to consider the Master's Degree as the first professional degree, and we think that the additional year for a Master's degree without an assistantship (typically close to two for a student on an assistantship) makes a big difference. Our Practice Oriented Masters Degree program seems to be an excellent solution for a student not wanting to pursue a research career.

However, when industry needs new engineers, they urge our students to go to work directly upon obtaining the BS degree. Some of our brightest students have done this and then gotten very disillusioned by their initial assignments. Our impression is that they expected a job more typical of a student with an MS. For our best students, we don't think that company reimbursed tuition to attend school at night for several years is the best choice. We get many requests to write letters of recommendation for students after they've spent about two years in industry to go to graduate schools in other fields. Law and medicine are two favorite areas. Industry must understand the world is different. Not many of today's students are willing to plot data for two years. We can address engineering education issues, but industry has to react to the changing culture.

Conclusions

We understand that industry wants better engineers: universities want to produce them! But everyone needs to understand the environment, we really *are* asking a lot of today's student. We think that Perry's model is closely related to the Boeing "attribute" chart and Nicolai's perception of the problems with education. Applied aerodynamics requires a level of maturity and sophistication that an average student doesn't acquire by the time he earns a BS degree. We need to emphasize the need for the Master's degree to be the first real engineering degree. This is the plan at MIT. Industry is not helping us in this regard.

We can remove some of the impediments to learning aerodynamics by eliminating programming barriers through the use of modern methods such as web-based simulations using Java and Mathematica Notebooks. We also use the web to ease the delivery of other course materials. This includes delivery of custom course notes in PDF format, and making traditional aerodynamics codes available for download off the web. The use of email seems to improve communications. By making most of this material universally available, students can return to the sites when they need to review the material after they graduate and are working. This might encourage life-long learning by providing a starting point for review and pointers to more information. Digital textbooks can include animated sequences and embedded interactive examples. The recent digital textbook by Ilan Kroo is an example. In short, most practicing engineers would not recognize today's "classroom" environment.

We've provided web site addresses for the examples cited. To assist the interested reader, we've put a PDF file of this paper on our web site, with color figures and links to the web sites so that the reader can explore the examples directly. This can be found at:

http://www.aoe.vt.edu/aoe/faculty/Mason_f/MRRpubs98.html

An assessment of the effectiveness of the use of this technology will require several years, when industry starts to gain experience with students that have had the opportunity to learn aerodynamics using these approaches. We expect a positive reaction by industry.

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Table 1

Perry's Theory of Development, from Wankat and Oreovicz, *Teaching Engineering*

- Overall progression: from dualistic (right vs wrong) to a relativistic viewpoint
- Students cannot understand or answer questions which are too far above them

Stage	**Characteristic**	**Students Idea of a Good Instructor**
1. Basic Duality	Facts, solutions, *etc*. are either right or wrong.	
2. Dualism: Multiplicity Prelegitimate	Students perceive that a multiplicity exists but still have a basic dualistic view of the world. There is a right and wrong. Multiple views or indications that there are "gray" areas are either wrong or interpreted as authorities playing games. Engineering students prefer engineering classes to humanities classes. They can solve closed-end problems with a single right answer.	Want teacher to be the source of correct knowledge and to deliver that knowledge without confusing the issues. A good teacher presents a logical, structured lecture and gives students a chance to practice their skills. The student can demonstrate that he or she has the right knowledge. From the student's viewpoint a fair test should be very similar to the homework.

Few challenges in engineering school provide motivation to move students to level 3 or 4, undergrads often taught as if everything is known

3. Multiplicity Subordinate or Early Multiplicity Level 3: Can practice engineering *To be a leader: Higher level required*	Multiplicity has become unavoidable even in hard science and engineering. There is still one right answer, but it may be unknown by authority. Student first realizes that in some areas knowledge is "fuzzy". Honest hard work is no longer guaranteed to produce correct answers. Good grades seem to be based on "good expressions".	The big question is: "What does he want?" Methods for evaluating becomes very important. Students want amount of effort put into something to count. A good teacher clearly explains methods used for determining the right answer even if they do not (temporarily) know it. Presents very clearly defined criteria for evaluation.

severe stress for students in a design course where multiple answers are expected and students are expected to function in a world with multiple answers

Engineering schools : at least level 3 for undergraduate schools OK

4. Complex Dualism and Advanced Multiplicity	Students try to retain right vs wrong position, but realize that there are areas of legitimate uncertainty and diversity of opinion. Solve problems cleverly and correctly, may lack vision about relative importance of problems.	A problem, especially in design: Often teach at level 5, students at 2 or 3.

Engineering schools : at least level 4 for graduate students OK

5. Relativism	A revolutionary switch, world is full of possibilities, relativism becomes the norm, absolutes are special cases, there does not appear to be a way to choose. Level 5 can appear "cold", life choices second guessed. Should move through this stage quickly.	Acts as a source of expertise, but does not know all the answers since many are unknowable. Helps students become adept at forming rules to develop reasonable and likely solution or solution paths. (It is important for instructor to show that good opinions are supported by reasons)
6. Relativism: Commitment Foreseen	Starts to commit to professional career, starts to develop maturity and competence.	
7-9. Levels of Commitment	Takes responsibility for one's self, mature stages of development, true competence.	Instructor needs to provide freedom so that students can learn what they need to learn.

Harvard liberal arts students said to attain level 7 or 8 at graduation

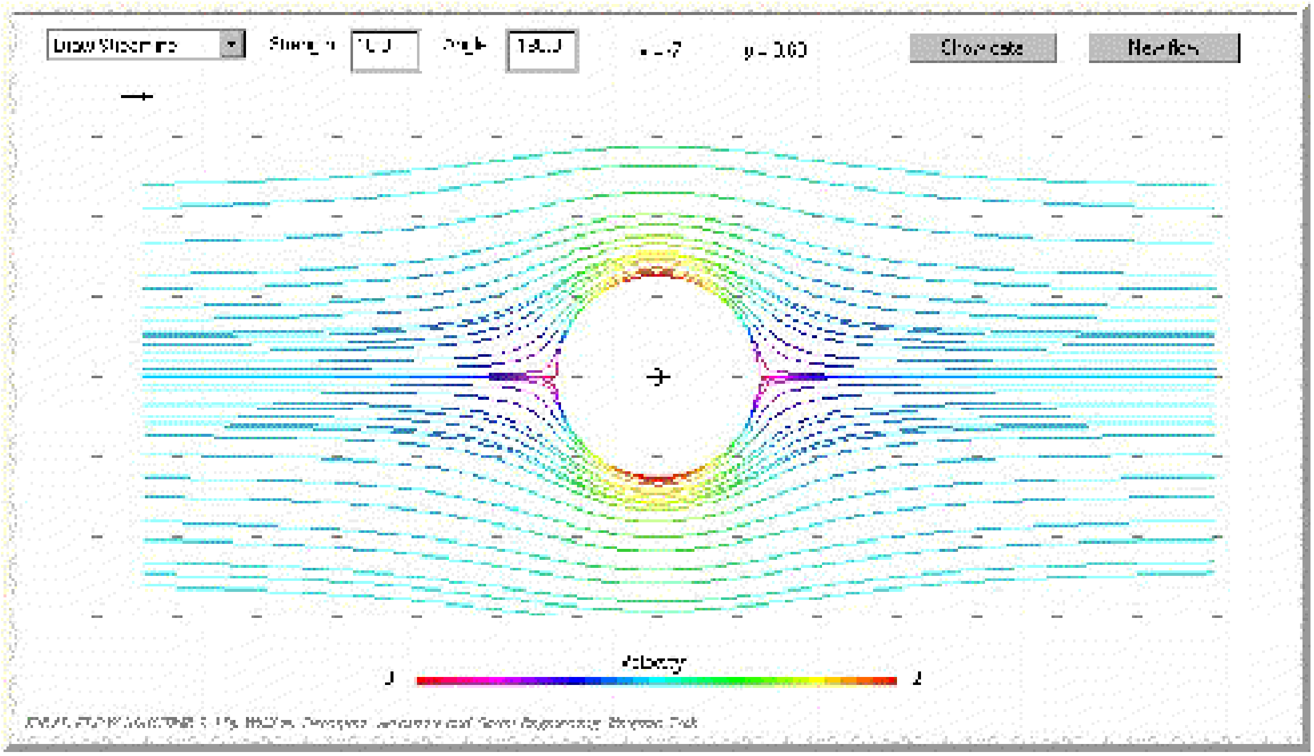

Figure 1. Example of the Ideal Flow Machine

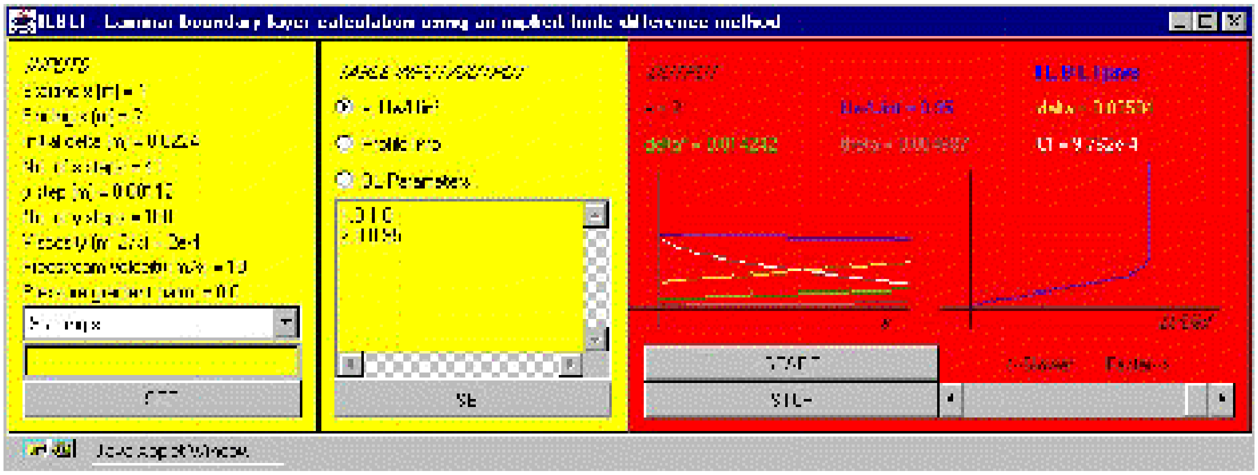

Figure 2. Example Java calculation of the boundary layer