Knowledge Representation, Content Indexing and Effective Teaching of Fluid Mechanics Using Web-Based Content

by

Katarzyna M. Niewiadomska

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Author ....
Department of Ocean Engineering
June 10, 2002

Certified by ....
Dick K.P. Yue
Associate Dean of Engineering and Professor of Hydrodynamics and
Ocean Engineering at MIT
Thesis Supervisor

Accepted by ....
Henrik Schmidt
Chairman, Departmental Committee on Graduate Students

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Abstract

As educational information on the web grows exponentially, and the learning focus shifts to the student, it has become increasingly difficult to navigate efficiently through the vast amounts of material available on-line. Teaching conceptual and qualitative material *effectively* while leveraging the content efficiently has long been an elusive goal for many researchers. The purpose of this study is to determine a method of augmenting student experiences in beginner fluid mechanics classes by tailoring and customizing a course to the individual user's characteristics using web-based content.

This thesis focuses on defining the key attributes that relate effective teaching to successful learning and then develops a conceptual methodology for implementing a web-based learning module that is continuously customized and dynamically delivered to individual users depending on their variable characteristics. The approach involves first monitoring performance, learning style and other characteristics of graduate students in an introductory hydrodynamics class then determining which characteristics are dependent and how they affect student academic performance. Next, incorporating results from the first step, a method for customized dynamic delivery (CDD) is developed. Preliminary tests were performed to determine the efficiency and benefits of such a module.

It was determined that students' academic performance and class satisfaction is highly dependent on their learning styles, background knowledge and field. Performance and satisfaction are also highly correlated to the learning style of the professor teaching, and that different students require different lectures, activities and assessment techniques to receive an accurate evaluation.

In conclusion, the topic of CDD warrants extensive additional research due to it's potential benefit in augmenting classroom experiences and self-motivated learning.

Thesis Supervisor: Dick K.P. Yue
Title: Associate Dean of Engineering and Professor of Hydrodynamics and Ocean Engineering at MIT

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Chapter 1

Introduction

1.1 Background

The World Wide web has become one of the fastest and most frequently accessed sources of reference in today's dynamic world. Larger efforts than ever before are currently in progress to utilize the web for teaching and learning purposes. Many higher education institutions have converted a large amount of material into electronic format.

Many projects have recently surfaced with this specific goal in mind. Initiatives at the Massachusetts Institute of Technology include OpenCourseWare(OCW) [30] and I-Campus. OCW is a venture dedicated to placing lecture material from 500 courses on the web to be available within the next year. I-Campus is an alliance between MIT and Microsoft Research to enhance university education through information technology. Many consequent needs arise from the above mentioned projects in terms of their effective application and use. A need for learning efficacy must be explored and the ensuing educational value considered.

A sub-project of I-Campus is I-fluids, an initiative specific to the effective leveraging of multiple sources of fluid mechanics materials for students at the graduate level. Through the I-fluids projects, it was envisioned that in the future, students would supplement their education by interacting with a fluid mechanics module that accesses course material and multimedia from each department offering these courses, where the presentation of the information would be customized to the specific learning, background, area of interest, time and pace needs of the student.

The implementation of this vision causes many questions and issues to surface. The main focus was placed on pedagogical and technical issues. In this thesis, a number of fundamental pedagogical concerns were addressed and studied in the specific instance of graduate students taking introductory fluid mechanics. Next, some technical questions were investigated, and a framework for a prospective module designed and tested.

Pedagogical results show that:

1. There is a high correlation between
   - primary teaching style and student learning style;
   - Teaching style and course satisfaction and academic performance;
2. Low correlation between secondary instructor's teaching styles and student performance and satisfaction;
3. Different course aspects such as labs, problem sets and lectures target different learning styles
4. Student knowledge background and field affect time spent on problem sets and academic performance of students; and
5. Different types of problems are preferred by different learning styles, which helps in defining a problem specific to a learning style.

Technical results show that in a limited setting, by restricting the number of possible references, a customized dynamically deliverable module produces reasonable results. Many issues have been more clearly defined and areas for study made clear.

1.2 The Drive for Improvement

For years, various forms of Computer Aided Learning (CAL) have been making their way into higher education environments, and most recently the World Wide Web has begun to dominate. As a platform that is used to integrate and deliver information in the form of text, audio, visuals, simulations, interactive models and videoconferencing, the web has become one of the most promising forms of Computer Aided Learning and one of the most widespread. The web is currently being used for a wide range of educational activities in engineering, from simply posting lectures and material online as an on-site class supplement to having simulated laboratories, experiments and group activities during class.

Many higher education institutions have converted a large amount of material into electronic format. I-fluids is an application specific to the effective leveraging of multiple sources of fluid mechanics materials to graduate-level students.

Planning the implementation of this vision brings to the surface various questions and issues. An implementation of a customizable, dynamic learning module, according to available literature, has not emerged yet.

Many educational and technical components of such a complex unit have already been researched, however, the goal of providing this module to first year graduate students taking fluid mechanics leaves many more pedagogical and technical questions unanswered.

1. How are graduate students affected by teaching techniques?

2. In fluid mechanics classes, do graduate students have a preference to different components of the class depending on their learning styles?

3. What student characteristics predominantly impact academic performance?

4. Can such a module be implemented? If so, in what context and with what restrictions?

5. Can the same effective teaching characteristics as those of an in-class instructor be used, and if so, will they still be effective?

6. Can each lecture really be customized to individual users?

1.3 The Problem in Engineering Education

Instructors of graduate level courses often expect students to have already covered a certain amount of basic material. As a result, they believe they can forego repeating the material and move on to more advanced and most likely more interesting, field related and challenging topics.

In addition, many professors would like to borrow, utilize and/or draw on material used by their colleagues in different fields and with different applications to further demonstrate the usefulness of the concept, the applications of the theory or the broad significance of the idea in other domains.

The problem that many beginning graduate students face during their first year or two with classes is the large gap in their knowledge with regard to what is being taught. Many students come from different disciplines, different cultures, have widely varying learning styles and different levels of proficiency in material learned at the undergraduate level. This results in different starting points, different progress rates and ultimately different levels of satisfaction and academic progress and performance.

Graduate students often welcome the opportunity to be exposed to more advanced material, particularly students who have a strong background in their field of study. However, students and instructors alike forget that graduate students often change departments and are in programs that differ from their undergraduate specialization.

This however, is not the only reason for divergence among graduate student development in the same class. Students from the same undergraduate program but from different undergraduate institutions, cultures, or countries often are taught varying degrees of the basic material which they are required to know.

Finally, students who have spent several years applying their knowledge in industry have a firmer grasp on the physical applications of their engineering field but have simply forgotten basics that they have not had the opportunity to use to date.

1.3.1 The Dilemma

As a result of the above described scenario, a dilemma prominent in many of today's graduate classrooms emerges. If classes move too slow, advanced students are held back by sitting in on classes where the material is more than familiar while the remaining students are given the chance to learn the material they have been missing out so far. If the classes move too fast, the advanced students are kept interested and motivated while the less prepared students with different backgrounds cannot keep up with the class and the gaps in their knowledge only get larger.

In both situations, the students are left frustrated, and often the professors are forced to compromise midway and settle for a mediocre class with lukewarm enthusiasm for either approach from different ends of the spectrum.

1.4 Problem: Effective Use of Abundant Web Content

"CAMBRIDGE, Mass. – MIT President Charles M. Vest has announced that the Massachusetts Institute of Technology will make the materials for nearly all its courses freely available on the Internet over the next ten years." –MIT News (See http://web.mit.edu/newsoffice/nr/2001/ocw.html)

"Simply put, OpenCourseWare is a natural marriage of American higher education and the capabilities of the World Wide We" –Charles M. Vest

"OpenCourseWare combines two things: the traditional openness and outreach and democratizing influence of American education and the ability of the Web to make vast amounts of information instantly available." –Charles M. Vest

Projects such as OpencourseWare, that set out to 'webatize' many of their classroom resources are ongoing throughout most universities worldwide. In the case of MIT, the projected time line is to have 500 courses worth of material available within the next year.

With this large influx of information on the web, adding to the already vast amounts of educational material available electronically, some questions relevant to students and instructors alike immediately arise.

Will this material be useful as an entity to any one person? Can it be used effectively for educational and informative purposes? Will the time and effort it takes to search through this material far outweigh the benefits?

In addition, materials on the WWW today can no longer just be placed there and forgotten. For this material to be accessed by any significant number of users, it must be represented appropriately, it must have the capacity for significant manipulation and must be effectively presented.

Therefore, focusing particularly on graduate education in fluid mechanics, can we find a mechanism that effectively represents, retrieves and delivers fluid mechanics information in a coherent sequence that results in the educational advancement of the user via the WWW?

1.5 Solution: Methods of representation, indexing and presentation, dynamic and customized

One solution proposed is the development of an electronic module that accesses a large pre-cataloged database of information spanning multiple disciplines and difficulty levels. Upon user access, this module would determine *who* the user is and what his/her affecting characteristics are and what the user wants to learn. Using this information, the module would access different pieces of the information best suiting the user's characteristics and present them to the user in a coherent and sequential manner. As the user learns more, the user characteristics are updated and the learning process continues.

This thesis describes the effects of student and teacher characteristics on learning, and outlines a solution for effectively leveraging web-based content to incorporate these attributes. A discussion of the issues that arise in the development of such a module is included, in addition to charting some of the topics for future research.

1.6 Definitions

Some important definitions below will help in understanding the terminology used in the following chapters.

"Customize: to build, fit, or alter according to individual specifications." From Merriam-Webster's Collegiate Dictionary (M.W.C.D.)[26]

Thus Customized learning modules indicate that the learning path is built to fit the individual's specifications, characteristics and needs.

"Dynamical: marked by usually continuous and productive activity or change." [26, M.W.C.D.]

Dynamic delivery is a continually changing delivery process that is actively modifying the content as the user's needs change and his/her knowledge develops, resulting in higher learning productivity.

"Effective: producing a decided, decisive, or desired effect." [26, M.W.C.D.]

So by effective teaching, we then mean that the process of teaching produces the desired effect in the student: maximizing learning.

Finally, *content leveraging* is the term we use to define the effective and efficient manipulation of large amounts of web content using our module to maximize student learning.

Chapter 2

The World Wide Web and Education

2.1 The Growth of the WWW in education

In the dynamic world of today change is seen as a desirable phenomenon, the task of predicting the future impacts of new technology is as difficult as ever. The arrival of the World Wide Web (WWW) is seen by many as the latest hope for a technological revolution in educational delivery. However, most forecasts of an impending revolution in educational practice have proved to be either short lived or non-events.

Consider some of the more positive comments on particular educational technologies:

"The intention was to break down the walls of the classroom and bring the world in" [6] describing the promise of post-World War 2 radio.

"Teachers are faced by a rising tide of technological hardware... the tape recorder is still the most widely available, the most flexible and useful." [17]

The legitimacy and acceptance of commercial feature films in the history curriculum is beyond question". Prof Stuart Samuels, quoted in Murray, 1979 [25].

"Despite all the advances in technology, the most widely used visual aid is still the overhead projector." [5]

Innovations like those mentioned above continue to emerge from time to time, but while they all have their faithful followers and adherents, little has changed in the teaching and learning process and after a brief period of flirtation with some new technology, things usually go back to normal [11].

Technologies that become firmly established typically follow the growth pattern shown in Figure 2-1 as described by Nolan [28].

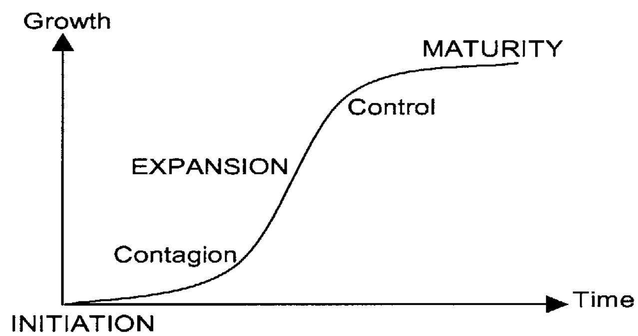


Figure 2-1: Nolan Technology Growth Curve

In the initiation stage, a few committed individuals grapple with the technology in trying to meet basic needs. There is little planning and relatively little management control. Following this, provided others become convinced of the value of the technology, a contagious growth takes place, typically so fast that there is a lack of control over the expansion. The expansion is then brought under control, often with over-reaction, until finally the needs of management and users are integrated and a balanced mature position is reached.

With WWW access, an explosion in access is taking place and this growth is already being controlled with special education networks where some censorship can be exercised over material available.

So why did instructors decide to use the WWW as part of their courses? Brown [4] lists five reasons for creating hyper-documents such as Web pages. These are:

- as a piece of personal research
- as a piece of creativity
- as a contribution to the subject

- to save staff time
- improve the quality of learning.

Certainly many educators find the Web a great opportunity to explore how this new technology can be used to supplement their courses while providing a creative outlet. In addition, educators find that using the web as a supplemental tool improves the quality of learning by adding an element of variety to existing methods.

2.2 Education and Teaching Via the Web

While much of the previous educational technology was designed to increase the power and effectiveness of lecture style presentations, more recent innovations have often been centered around the ability to foster self-directed learning. Traditional techniques have gathered a number of students together in one place and at one time, whereas computer-aided learning (CAL) and the WWW have permitted students to work in their own time and place and at their own pace.

Using the WWW as an instructional tool offers various advantages (and disadvantages) to both the student and the instructor. Some advantages to students being

- Flexible time and place
- Additional resources via the internet
- Improved activities because of relaxation and less restriction
- Self-paced
- Simple
- Consistent environment with no variables due to class size, space accommodations, differences in instructor presentation, mood, etc...
- Comprehensive coverage combining full-motion video, audio, presentation slides, templates and text

Some of the dominant disadvantages from both the learner and educator's perspective is the more static nature of the instruction despite many efforts to create personalized user-oriented modules. Learning via the Web is often impersonal, lacks warmth and the element of human contact. In addition, the transient nature of Web pages presents issues of stability and change without warning. Part of the appeal of the WWW is the ability to build on local material by national and international links to provide access to the best material one can locate. Such links based on the academic's knowledge of what is important and why provide an opportunity for deep learning [3].

Finally, despite the fact that searching the Web is easier than searching a library, students are required to employ various search methods and filter out much more useless information before finding material they are looking for. Their choice of web browser and search engine will severely affect their results. The growing number of search engines matches the growing number of different techniques used for indexing and ranking documents. Some search only page titles or abstracts, others perform full text searches, and others still are dynamic and continually updated. Subsequent to these various search methods arises the issue of page authenticity. The anonymity provided by the web conceals the source of the document and brings the question of validity to the surface.

Knowledge and information comprise the basic element of the instructional sector. The world of information is changing rapidly and the growth and availability of material has increased exponentially and in parallel with the evolution and encroachment of the WWW on our daily lives. Many higher education institutions over the past several years have embarked on ambitious projects to promote accelerated learning, the modularization of courses, and the integration of information technology in appropriate courses in hope that the initiative would empower students to become self-directed, life-long learners.

Northwest Missouri State University has embarked on a project that will reconfigure courses into modules in hopes that this will enhance the learning process and allow learners the opportunity to enter the curriculum at a point appropriate to their

Course Level	*Course Integration*
Informational	Standard course material and information about the course is published on a web page
Supplemental	Additional course material is posted on the web page, with links to related sites
Dependent	Major components of the instructional process use the web for delivery
Fully Developed	Entire course is delivered through the web

Table 2.1: Curriculum Integration Levels Identified by Oregon State

prior knowledge and actively pursue their learning at a time, place, and style that suits them best [15]. Oregon State has also initiated a web learning program with parallel goals in mind.

Similarly, the MIT Educational Media Creation Center is assisting a multi-disciplinary project in Fluid Mechanics titled: "A School-wide Modular Program for Fluid Mechanics", proposed by members of the Aerospace, Chemical, Civil and Environmental, Mechanical and Ocean Engineering Departments. It was proposed that the program would consist of a number of modules representing the fundamental topics. These modules would then be integrated to form coherent courses to suit the educational purpose of individual students in different departments of the School of Engineering. The completed program could then be used as the foundation for more advanced and specialized modules to be built.

The University of Oregon has identified four curriculum integration levels (Table 2.1) for their courses offered over the World Wide Web. Each level builds on the previous level and incorporates more web integration.

Many institutions believe that now is the optimal time to improve the efficiency and quality of traditional methods of teaching and learning. In particular, it is clear that the web can provide easy access to *virtual* experiences and can help illustrate problems and engineering applications. Equally importantly, it can provide the interactive, trial-and-error learning mode that can better cultivate the students' ability to think, to explore and to innovate.

2.3 Instruction before and after the WWW

Before the emergence of the computer and subsequently the World Wide Web, conventional teaching methods involved chalk and a blackboard, a slide projector and the occasional Microsoft Powerpoint presentation when a little creativity was put forth.

Student learning activities, as listed by Godfrey [11], consisted primarily of:

- attending lectures
- receiving handouts of lecture summaries
- making notes
- asking questions
- challenging statements made by the lecturer
- attending tutorials
- collaborating with other students
- visiting libraries
- photocopying books and journal articles
- copying other students lecture notes
- private study
- reading collected material
- organizing material
- and annotating and highlighting material.

The most popular technologies used by students were the photocopier, the calculator and the high-lighter pen.

Today, virtually every class has at least a web-site containing meeting time and syllabus information if not a fully functional web-site where material is posted and information provided or exchanged. This dramatic change from conventional learning only reinforces the need to develop the web as a better educational tool for more constructive and effective learning.

2.4 Why Choose Fluid Mechanics?

The discipline of Fluid Dynamics plays a central role in many branches of engineering and science. It is important in the engineering of land vehicles, ships and aircraft as well as many other mechanical and industrial processes. Fluid motion in air and water affect our environment while fluid transport and mixing are responsible for biological processes in nature and in the human body. Because of the inherently multi-faceted multi-disciplinary nature of the subject and its broad importance to applications in many fields, fluid mechanics provides the ideal test bed for our module.

At MIT, 31 graduate-level Fluid Mechanics subjects are taught in five of the seven Engineering School departments, 22 in two of the School of Science departments and in the School of Architecture [23]. As a result, efforts in creating courses are duplicated and student interdisciplinary interactions that would enrich student development are reduced.

Over the years, many approaches to teaching fluid mechanics have been developed and supported with equally as many examples spanning most fields of interest. These characteristics will facilitate the creation of the content database by simply drawing together the instruction and methods of various instructors in varying fields.

2.5 What is Effective Teaching?

We mentioned earlier that effective teaching is the key to succeeding in transferring information from instructor to students. In effective teaching, Kember [18]defines five approaches that instructors use for effective teaching. These are imparting information, transmitting knowledge, student-teacher interaction, facilitating understanding and finally bringing about conceptual change and intellectual development. These approaches demonstrate the relationships between instructor, learner and content, generally bringing about 'effective teaching', but what are some of the characteristics that allow these adjustments to occur?

2.5.1 Characteristics of Effective Teaching

Effective teaching techniques must be employed so that the benefit of computer aided learning is not overshadowed by the benefit of having a live professor in the class. Not all features of an effective instructor can be incorporated into an online tutor, however, the more features available, the more superior the result.

There are endless adjectives that characterize effective teaching. The characteristics below are some of the most prominent in today's teachers and that is why they were selected. Keep in mind that the list can always be expanded as long as there exists a parallel in the computing world.

1. Richness of Content/Knowledge

   One of the foremost reasons an educator is effective is due to the vast knowledge and experience they have accumulated. Richness of content is illustrated best by a diversity in teaching aids, such as lecture notes and examples, exercises, interactive and visualization models, experimental software, diagrams, illustrations, photographs, images, animations and videos.

2. Needs Anticipation

   Anticipating student needs is another important trait that many 'good' teachers display. Deciding what method of presentation to use for each student depending on the student's characteristics and past performance reduces the time and effort spent on trial and error methods and targets the student's optimal learning propensity.

3. Customization

   Customizing the content is the most natural step taken after anticipating the student's needs. The requirements are determined and the course is then modified accordingly to meet the needs. This ensures that each class progresses at the pace the students are most comfortable with.

4. Dynamic Delivery

   Subsequently, dynamic delivery of this customized content falls into place. The educator determines how much of the material to present and to what depths of involvement to go into. He/She determines the pace at which to progress and, depending on the students, which elements to reinforce. This schedule management is only marginally determined in advance and is reassessed frequently as the class develops.

5. Student Assessment

   Throughout the whole process, the educator is constantly assessing student understanding and progress to determine what has been understood and to what extent. Assessment also occurs through quizzes, exams, homework, classwork and oral questions from both the instructor and the students.

2.6 Previous Work Along These Lines

Many universities have begun and continue to convert many of their courses into electronic format for use on the Web. Many of these projects can easily be categorized according to Kember's [18] teaching approaches.

Some projects simply aim to make available course material on the Web, such as MIT's OpenCourseWare [30]. Northwest Missouri State University has focused a little more on transmitting structured knowledge rather than simple transmission in their Accelerated Modular Learning Project [15], in which they aim to modularize the content into structures based on the relevance and importance to the material being taught.

MIT's PIVoT (Physics Interactive Video Tutor)[32] is a web-based system that aims to facilitate understanding of the basic concepts in physics, where students can watch videos of lectures, ask questions, take quizzes and are essentially tutored in the subject matter. This course focuses on introductory physics. Temple university has created a similar system in Calculus, COW (Calculus On the Web)[29] focusing on virtual student-teacher interaction and acting as a guide in learning calculus and emphasizing student discovery.

Purdue University acknowledges learner diversity and currently structures some of their live in-class engineering courses accordingly, by providing various activities that supplement the traditional lecture and recitation sessions. An effort is currently in progress to parallel this process on the Web.

Many more initiatives today are focusing on the development of web-based schemes that focus on the conceptual change and intellectual development of the individual, viewing students as individuals and recognizing that they are not a homogeneous entity. These approaches often involve attempts at customization. Industry has taken a lead in this mission and companies such a IBM, Microsoft Research and Infolenz have begun marketing scalable managed environments that aim to customize and distribute learning effectively. Most of these services however are

1. designed by technology specialists rather than domain experts,
2. designed for company personnel requiring training rather than college level students
3. are customized to *groups* of individuals such as managers, personal assistants, etc... rather than to *individuals.*

The Advanced Distributed Learning (ADL) initiative is a collaborative effort between government, industry and academia to establish a new distributed learning environment that permits the inter-operability of learning tools and course content on a global scale. ADL's vision is to provide access to the highest quality education and training, tailored to individual needs, delivered cost-effectively anywhere, anytime. [24]

The Sharable Content Object Reference Model (SCORM) created by ADL aims to unify implementations and specifications adapted from multiple learning sources over the web. This effort is the closest implementation to our goals so far. However, it does not, as yet, create the content to be used. SCORM could be a valuable platform in the future that would enable and promote unified usage of multiple content databases (if these databases are readily available in universal format).

Chapter 3

Pedagogical Characteristics Affecting Student Learning: Applications in the Fluid Mechanics Classroom

The primary purpose of this chapter is to determine the major characteristics affecting student learning in order to incorporate these in the design and delivery of web-based content. Students in today's graduate level classrooms often display widely varying characteristics that radically affect the amount of material they learn. Although student characteristics have been widely studied in the more traditional teaching-learning environments, educators have just begun exploring the applications in web-based teaching techniques. This chapter first describes the characteristics under study, and then reports the results of a study designed to measure and more clearly define the value of these characteristics with relation to a graduate fluid mechanics classroom. Through these studies, we try to answer the following questions:

1. How are graduate students affected by teaching techniques?

2. In fluid mechanics classes, do graduate students have a preference to different components of the class depending on their learning styles?

3. What student characteristics predominantly impact academic performance?

The chapter concludes with a description of how guidelines from the study can be adopted for use with customizing web-based instruction.

3.1 Introduction

In recent years, approaches to teaching have shifted considerably and have led to a greater differentiation between teaching and learning. While studies on improving teaching have been ongoing for many years, only recently have studies on improving learning been initiated. More and more researchers today are looking into what characteristics affect a student's learning curve given that the teaching techniques are close to optimal.

A variety of student characteristics impact a student's performance and ultimately his/her achievement. According to Dr. William G. Huitt [16] from the Department of Psychology at Valdosta State University, the main characteristics are:

- Intelligence, Achievement and Prior Knowledge
- Learning Style
- Cognitive Development
- Gender
- Race
- Moral and Character Development

This list has been modified to include only the characteristics pertinent to this study.

3.2 Student Attributes Affecting Learning

In our experiments, we have focused on a first year graduate level classroom that teaches introductory fluid mechanics. This class assumes an undergraduate fluid mechanics course as a prerequisite. Considering that many first year grads have *never* taken a fluids course, and that many come from unrelated fields, we have modified this list to include additional characteristics that take these factors into account.

In this study, we have referred to these characteristics as attributes. These attributes are:

Basic Knowledge Background: This characteristic represents the basic fluid mechanics knowledge that the student already has. On a given scale, it shows whether, and how much, basic undergraduate fluids the student has taken. The scale however is multidimensional, showing not only background knowledge in fluid mechanics, but also knowledge of other categories required for a better understanding of fluids.

Fluid mechanics is better understood if the student has an intermediate knowledge of topics such as dynamics, calculus, vector analysis and differential equations.

Undergraduate Field: An introductory level course, particularly in fluid mechanics which is a topic that is taught in almost every discipline in engineering, generally brings together students from every field in engineering including nuclear, chemical, coastal and electrical engineering. In addition, various students from other fields in science such as math and physics, marine sciences and materials science are often found taking these classes as well.

Academic Performance: A student's prior academic performance is often a factor that is overlooked in a student's current academic achievements. A good or bad performance often affects a student positively or negatively particularly during test taking and quizzes.

Learning Style: Student learning styles are probably one of the most researched factors affecting student cognition and learning rate. Many studies have been performed on student learning styles with many different categorizations made available. The most basic being the Visual, Auditory and Kinesthetic Learners.

These learning styles are most often targeted in elementary education. A number of people have tried to 'catalogue' the ranges of learning styles in different manners. Some of these are

- The Index of Learning Styles based on the Felder-Silverman model.
- McCarthy's 4MAT model explains learning in terms of the ways people perceive and process information. The Complete 4MAT System Model reflects four distinct phases of the learning cycle:
  1. Experiencing
  2. Conceptualizing
  3. Applying
  4. Creating
- Kolb [19, 20] showed that learning styles could be seen on a continuum running from:
  1. concrete experience
  2. reflective
  3. abstract conceptualization
  4. active experimentation
- Honey and Mumford's Learning Styles Questionnaire that reflect's Kolb's stages of learning but is less direct in questioning learning preferences.

Gender, Race and Culture: In 1968, William Perry did a study of male undergraduate New England college students. From this he isolated nine stages in a developmental thinking sequence that men go through. In a 1986 study Belenky et al.[2] discovered that women have different ways of thinking which they chose to characterize as possible 'ways of knowing' rather than stages of knowing, although women still progress through these 'ways of knowing' sequentially. Thus men and women indeed do have different 'thinking structures' that should be kept in mind.

Mean	*USA* $N = 862$	*Canada* $N = 46$	*Greece/Fem* $N = 228$	*Greece/Male* $N = 342$
Activist	9.9	8.5	12.5	11.0
Reflector	13.2	13.9	15.8	16.4
Theorist	12.8	13.6	12.4	14.1
Pragmatist	13.1	14.0	11.4	13.1

Table 3.1: Learning style norms for some countries from the Manual of Learning Styles

Mean	*France* $N = 51$	*Ger/Aus* $N = 53$	*Italy* $N = 28$	*Scand.* $N = 44$	*Switz* $N = 34$	*UK/Ire.* $N = 34$
Activist	10.7	9.9	10.9	12.1	11.8	12.0
Reflector	11.7	10.8	12.0	9.9	11.7	9.3
Theorist	12.7	11.3	13.7	9.9	11.7	10.7
Pragmatist	14.3	13.5	14.1	13.1	14.8	13.3

Table 3.2: Learning style norms for Eurpoean countries from Neil Habershon

However, according to the Manual of Learning Styles[27], some norms of random samples of males and females drawn from comparable populations of professional people were studied and suggest that there are no significant gender differences in learning styles. The mean shows females to be slightly more Activist while males were shown to have been slightly stronger preferences in Theorist and Pragmatist.

In addition, culture specific norms were also given (Tables 3.1 and 3.2) and show varying means and dominant learning style preferences. However, for the purposes of this study, culture specific differences will not be considered for simplicity.

Gender and race specific differences relating to the Honey and Mumford Learning Styles Questionnaire(LSQ) are negligible and will not be considered either.

The Honey and Mumford Learning Styles Model

Learning is a continuous process that is never compete. According to Honey and Mumford's *Manual of Learning Styles* [27], learning is a never ending process of experiencing, reviewing, concluding and planning. In each stage, the learner, has an experience, reviews this experience, concludes from the experience and plans the next steps to once again have an experience in a continuous and iterative process.

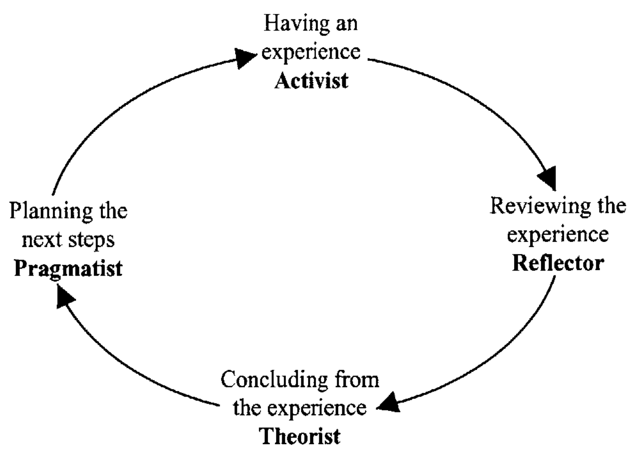


Figure 3-1: Honey and Mumford's Learning Cycle

These four stages are dependent and none is fully effective as a learning method without the support of the other stages. Many people however develop a preference to one or two particular styles that results in a distortion of the learning cycle. This lessens the effectiveness of the learning process and leads to a penchant towards certain characteristics favored by that style and ignoring important features of the other stages critical to effective and efficient learning.

A student's learning style not only gives insights to the student's learning preferences and character, but also provides a guide to adjusting the students' learning styles to a balanced one rather than a preferential one. Understanding a student's learning style is essential in determining the format of the material to be presented and the approach to be used.

An individual's learning style is a distinctive and habitual manner of acquiring knowledge, skills or aptitudes through study or experience and can be identified using a learning style inventory such as that described by Honey and Mumford. Four learning styles can be identified: 'Activists', 'Reflectors', 'Theorists' and 'Pragmatists'.

Individuals capable of using all of these learning styles are considered to be well-balanced effective learners. The majority of individuals have one or two preferred learning styles with the other styles being used to a lesser degree, if at all. Honey and Mumford, developed a learning questionnaire (LSQ) that allows individuals to be classified in terms of their strengths and weaknesses for each stage of the learning cycle. Using this classification system four distinct learning styles can be identified:

Activists Individuals who are usually enthusiastic when a concept is novel and exciting but tend to lose patience quickly. They are 'hands-on' learners that learn best from competitive activities. They respond well to challenges.

Reflectors Cautious individuals who consider their actions carefully before making a final decision. They are 'tell-me' learners who learn best when given time to prepare in advance.

Theorists Individuals who consider all alternatives and make conclusions from their experiences. They are 'convince-me' learners who usually attempt to fit their observations into a logical model. They learn best when required to understand complex problems.

Pragmatists Individuals who get impatient with too much reflection and like to experiment with new plans usually putting them into operation immediately, without too much discussion. They are 'show-me' learners who learn best when the link between the subject matter and the desired outcome is apparent or when there are obvious advantages to learning a given task.

The Learning Styles Questionnaire(LSQ) consists of eighty true/false questions that ask about a user's behavior and lifestyle rather than their learning style. A user's raw scores are converted into normalized scores using the Honey and Mumford model and finally the ranges of the scores determine the learning style. The final learning styles results are grouped into five categories; Very strong, Strong, Moderate, Low and Very low for each learning style. The student's scores fall in one of these ranges for each style, thus determining the dominance or lack thereof of that particular style in the student's character.

Learning styles are not exclusive and one student can have very strong or very low learning styles in all categories.

3.3 The Current Study

The general purpose of this study is to determine some major characteristics affecting student learning. In particular, it was hypothesized that a student's academic performance is affected by learning style, background knowledge and area of expertise. Thus a graduate student will perform better than another if the lecture is more geared towards his/her particular learning style and homework problems of different types will appeal to students with different learning styles. It was predicted that Reflectors would perform better on problem sets, Activists better in labs, Theorists better on exams, and pragmatists better on field related problems and finally, students with related undergraduate fields will perform better than others.

3.3.1 Method

In the process of customization, a three step process that helps determine relevant criteria is used.

First, understand the gap in the student's knowledge base, i.e. determine the background knowledge and what is missing. *What* do we need to teach?

Second, understand how to fill this gap, i.e. determine learning styles of student. *How* do we present this material?

Third, understand how to integrate previous and current knowledge to student experiences, i.e. determine student field of expertise. *Why* are we presenting this material?

Using the stages of customization as guidelines, the students' background knowledge, learning styles and field of expertise were determined. In addition, a mid-semester survey was administered halfway through the term to help determine student satisfaction with the instructors, the subject in general and the course components.

3.3.2 Participants and Materials

Thirty graduate students enrolled in a first year graduate fluid mechanics course participated in these surveys purely voluntarily. A web-site for the class was developed for the transmission of class information, assignments, surveys and lecture notes. This site can be viewed at http://web.mit.edu/13.021/www. The problem sets were posted on the assignments page of the web-site, and students were unable to access the assignments until the sign-in procedure was completed. The sign-in procedure included a basic demographic questionnaire and a link to Honey and Mumford's Learning Styles Software page. Students were required to fill out the survey, however the learning style questionnaire was optional and only 26 of the 30 students responded. The mid-semester survey was in paper format and handed out at the end of lecture.

3.3.3 Procedure

To acquire the data, several different approaches were taken depending on the data needed.

Background knowledge was determined via a problem set designed to test students in basic areas required for the class. See A. These areas were:

- Calculus
- Vector Analysis
- Differential Equations
- Fluid Mechanics and
- Dynamics

The problems were rated as easy, intermediate and difficult. Students either received a 1 or a 0 depending on whether they answered correct or wrong respectively. Each correct response was then weighted with the difficulty of the problem and a cumulative final score achieved. The problem set was designed by the teaching assistant for the class, a doctoral student specialized in fluid mechanics; the advantage being in using the same domain experts in designing the evaluation criteria and in grading. Raw data can be found in Appendix D.

Learning styles were evaluated on-line, using the Learning Styles Software [31]. The software is a computer adaptation of the original LSQ designed for web users. The entire questionnaire takes approximately 15 minutes to complete. The questionnaire avoids asking direct questions about a user's learning style and instead asks questions related to work experiences and forms of interaction with others in a working environment. The survey is submitted online and users can see and print their resulting learning styles ratings immediately. A copy of the questionnaire is found in Appendix A. Raw data can be found in D.

Field of expertise was simply filled out by each student during an online sign-in survey that polled students for class attendance, preferences in class recitation times, email address and of course undergraduate field of study.

The mid-semester survey required the students to rate their liking of the instructors, the subject in general, the difficulty of exams, and the time spent on homework. The ratings were on a scale of 1 to 7, where 7 was extremely satisfied, and 1 was extremely dissatisfied. A copy of the survey is available in A. Raw data is shown in Appendix D.

3.3.4 Results and Discussion

Effect of Teaching Techniques

The effect of teaching techniques were determined by two criteria, student academic performance, and student satisfaction. Students rated their satisfaction with the primary instructor, with the two secondary instructors, and with the subject in general.

Student Satisfaction	*Primary Instr.*	*Secondary Instr. A*	*Secondary Instr. B*
Pearson Correlation	0.91	0.26	0.33
Cronbach Alpha	0.99	0.90	0.93

Table 3.3: Student Satisfaction Correlation Table

Academic Performance	*Students with Matched LS*	*Satisfied Students*
Pearson Correlation	0.84	0.86
Cronbach Alpha	0.91	0.92

Table 3.4: Academic Performance Correlation Table

These surveys were anonymous and are therefore assumed to be unbiased. In addition, the primary instructor's teaching style was determined using his learning style as guideline and with input from both instructors and students. Academic performance was evaluated throughout the semester and the final grade for the class was used for the correlations. As the student satisfaction surveys were anonymous, it was necessary for us to try to correlate the percentage of students satisfied with the percentage of students who achieved the highest grades in the class.

Results in Table 3.3 show a very high correlation (Pearson coefficient $\rho = 0.91$) between the number of students satisfied with the subject in general to the number of students satisfied with the primary instructor. However correlations of student satisfaction to their satisfaction with the secondary instructors were much lower. See Table 3.3 for details.

A very high correlation ($\rho = 0.99$) was also found between the percentage of students satisfied with the class and the percentage of students whose learning style matches the instructor's teaching style.

The researchers conclude that students with Learning Styles strongly matched to the instructor's teaching style are generally more satisfied with the instructor and with the subject as a whole. In addition, these students achieve higher academic performance than their peers.

It is clear that after years of teaching the same class, the instructor has learned to customize his teaching style to the dominant learning style of the class. This characteristic shows that effective teaching includes components of on the spot needs assessment, and customization of the material depending on student characteristics.

Finally, student satisfaction levels with the different instructors are an indicator that students notice teaching style presented and gauge their class satisfaction partially on their satisfaction with the instructor. Note that the secondary instructors have had little to no teaching experience are are unable to adjust their presentation styles as effectively as the experienced instructor. Recall that academic performance is strongly tied to satisfaction with the instructor and course as a whole.

Learning Styles and Class Components

A typical engineering class consists of several learning components aimed at covering the subject from various angles. Typically a class consists of two to three oral lectures per week in which the lecturer delivers a topic and answers a few related questions; a once-a-week recitation component that allows much more time for interactive learning and problem solving where the teaching assistant covers ambiguous or tough topics, solves problems and answers student questions; finally, the laboratory component which tries to give the student a closer look at the physical and practical applications of the theory and principles involved.

Converting in-class activities into web-based material is possible, however, the pedagogical benefit of each is not yet clear. In trying to create an online classroom, or at least an electronic module that aims to emulate effective teaching and successfully customize and deliver content, these components and their relationship to student learning styles must be better understood. In recognizing the inclination of students to particular components according to their learning styles, the process of customization can be refined: determining the types of activities that students prefer can be paralleled electronically.

Another segment of the customization process involves determining the types of problems that different students prefer. In the class under study, each problem set consisted of a variety of problems based on major categories of the cognitive domain.

According to Gronlund [12], these are

- Knowledge
- Comprehension
- Application
- Analysis
- Synthesis
- Evaluation

The progress of each student on each problem was followed throughout the semester.

In this study, the hypothesis proposed was that different course aspects such as labs, problem sets and lectures target different learning styles. In addition, problems of different cognitive levels are preferred by differing learners.

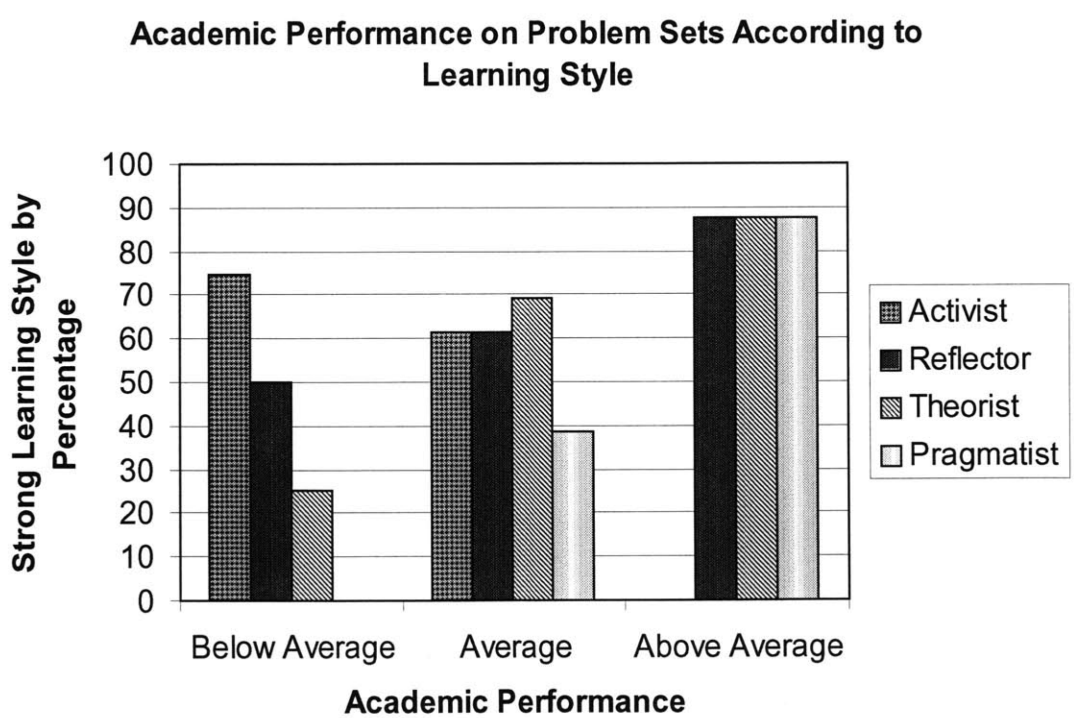


Figure 3-2: Performance on Problem Sets

Results on problem set performance (figure 3-2) show clearly that Activists perform predominantly below average and average, while none of the strong activists were seen to perform above class average on problem sets. Reflectors and Theorists seemed to follow generally a similar trend where a larger percentage of strong learners performed above average than below. As for Pragmatists, the highest percentages were found performing above average while no strong pragmatists performed below average.

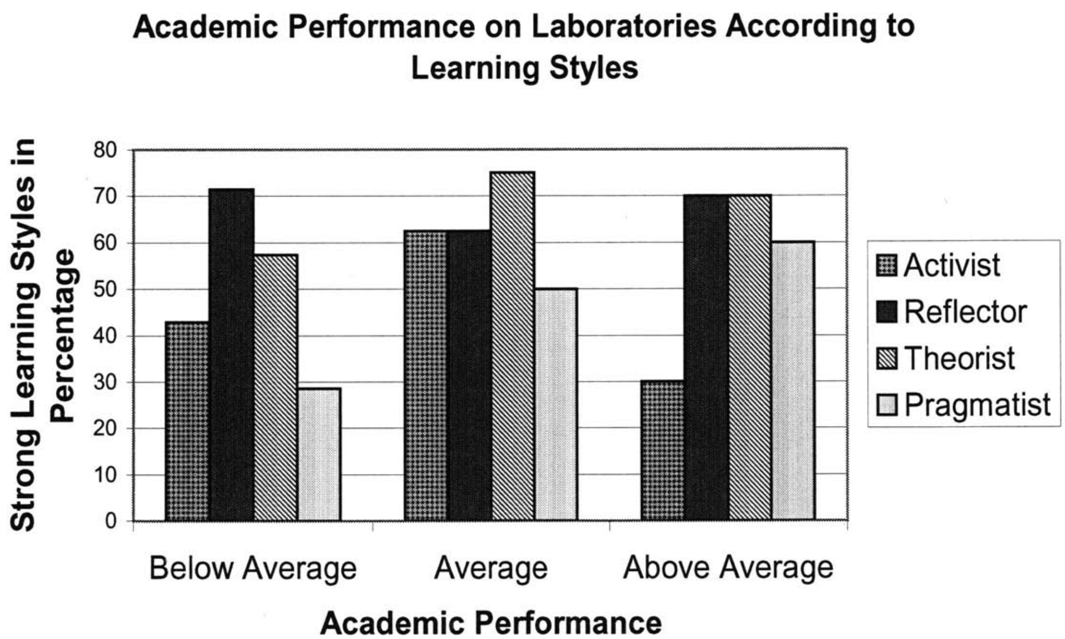


Figure 3-3: Performance on Laboratories

In comparing performance in the laboratory, (figure 3-3)it was found that strong Reflectors and Theorists performed equally. This result is inconclusive as to the relationship between laboratory performance and the Theorist and Reflector learning styles. Contrary to prediction, the majority of strong Activists performed average or below average in the lab component. One explanation for these unexpected results could be the fact that the lab involves more of an observation and analysis component rather than active experimentation. Students performed only parts of experiments and observed the rest. An additional reason could be the fact that all the lab grades were high with a class average of 91 percent. This leaves little room for above average performances.

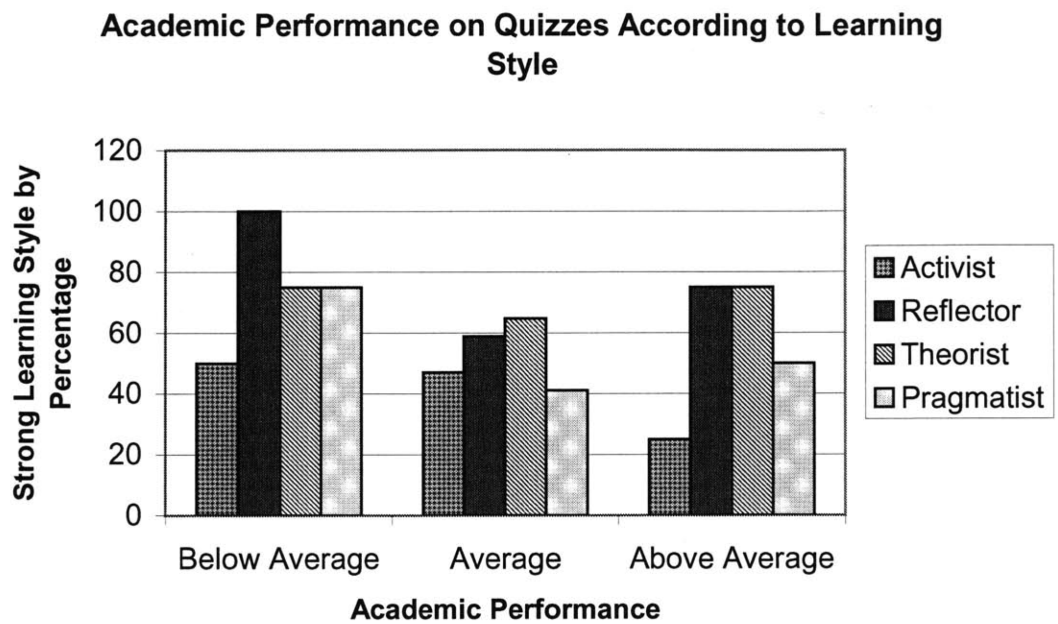


Figure 3-4: Performance on Quizzes

Quiz performances (figure 3-4) for strong Theorists again showed constant characteristics where there was no differentiation in performance depending on Learning Style. However, an interesting observation was that all the reflectors that scored below average were strong Reflectors. This reinforces the premise that reflectors do not perform very well under pressure and prefer a more laid back environment. Similarly, Activists and Pragmatists had the highest percentage of strong learners performing below average. These characteristics are consistent with prediction. Note that a particular percentage must always exist in all three categories as being a strong learner in one category does not prevent the user from being a strong learner in others as well. It is possible that a student has strong characteristics in all four styles.

The problems in each problem sets were categorized according to the list above, however, the problem sets included only the categories of knowledge, comprehension, application, analysis and synthesis. The results in fig 3-5 show that the best performers in knowledge, comprehension and application are the strong Activists with the

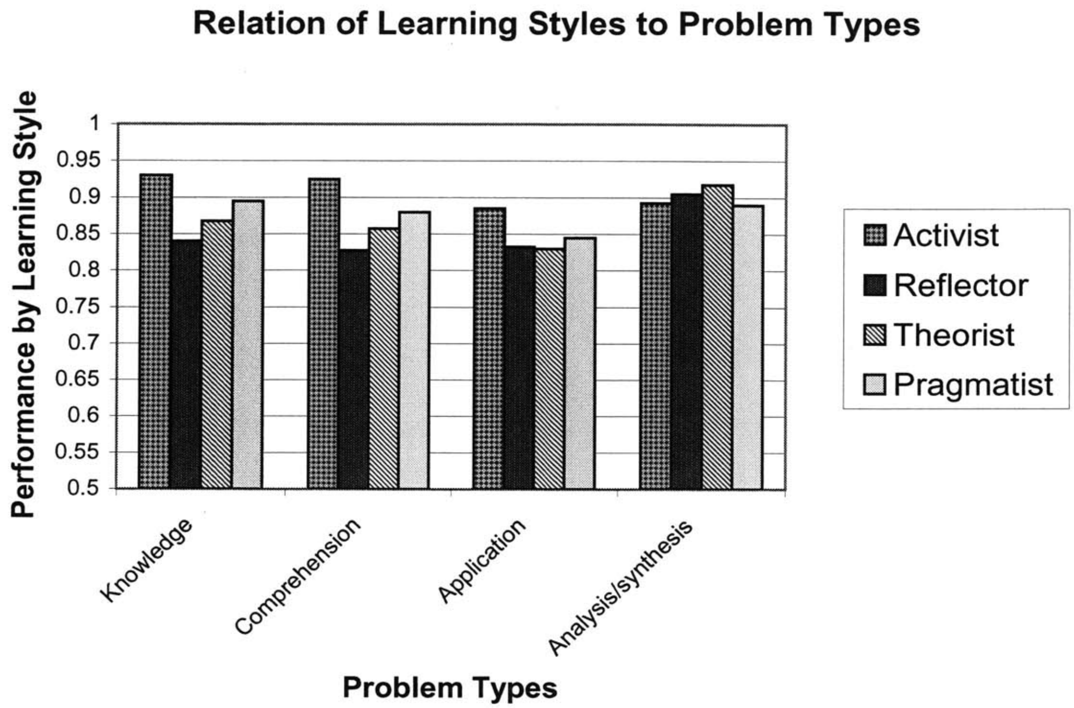


Figure 3-5: Performance on Problem Set Categories

pragmatists consistently a close second. However, in the categories that require an extension of theory, or the development of one's own, strong Theorists, and following closely, strong Reflectors achieved slightly higher scores than either Pragmatists or Activists. These results seem somewhat inconclusive however they are encouraging enough to warrant additional and more detailed research to better understand cognitive differences, if any, among the different learning styles.

It appears that evaluation methods on this front were clearly insufficient. In addition, results indicate that despite knowing conceptually what components a course should contain to suit different learning styles, there still exists a large gap in determining how exactly to design these components to target these learning styles.

Characteristics Affecting Academic Performance

Academic performance is generally affected by various factors, and not all are intuitively obvious. Simply because a student has a poor background in math does not mean that they will perform worse than a student with a strong mathematical background. Factors such as hours spent on homework, field of study, even student attitude and mood will affect the final academic performance.

In this section, we attempt to quantify some characteristics that may help in improving academic performance. Assuming no psychological effects on student performance, it was hypothesized that apart from learning styles, the two major factors affecting a student's academic performance are background knowledge and field of expertise.

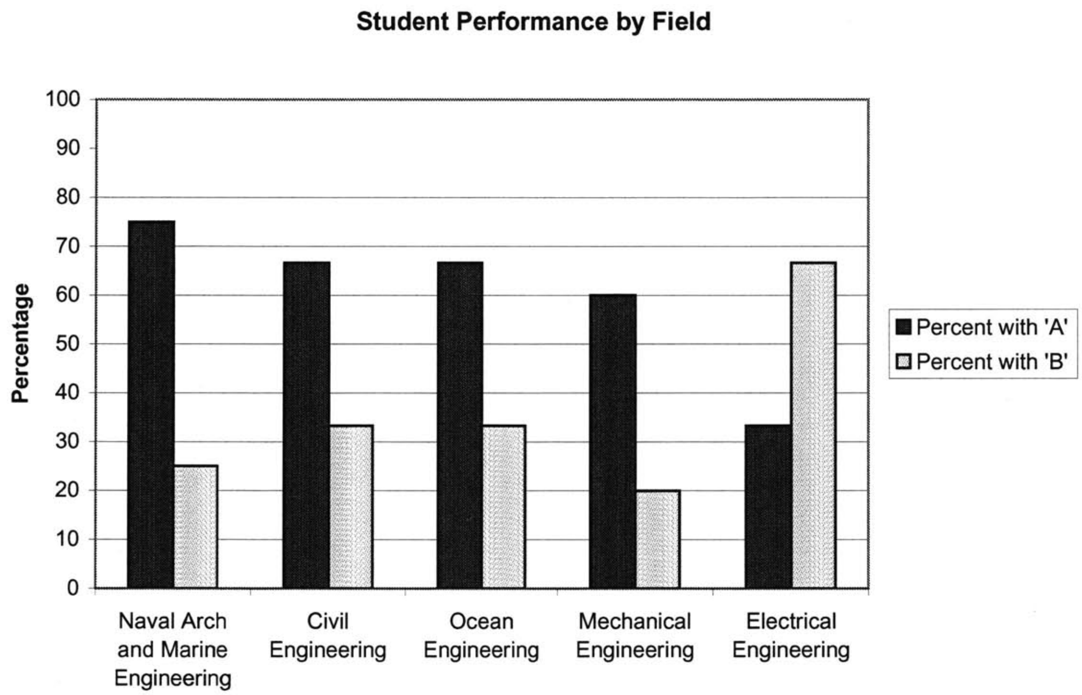


Figure 3-6: Academic Performance by Field

Fig 3-6 shows a plot of the class data relating percent of students from each field to the percentage of students who received A's and B's in the class.

Note that the fields that are closely related to marine hydrodynamics such as naval architecture and marine engineering had the highest percentage of students receiving A's. Similarly, ocean engineers and civil engineers also achieved high percentage of students with A's as both fields teach a considerable amount of fluid mechanics.

However, a mere 33 percent of electrical engineering students got A's, while a much larger percentage got B's.

The results seem to indicate that student's background fields affect their performance for more than one reason. Civil and mechanical engineers, despite their fields being unrelated to hydrodynamics, still scored comparably high quantities of A's, most likely due to their training, application areas and educational background. Both mechanical and civil engineers are required to learn some laws of fluid mechanics and much of the math used in hydrodynamics. Electrical engineers on the other hand are required to learn some mechanics but this does not include fluids. In cases like these, a customizable module that can reach back into the basics and present them anew may mean the difference between success and failure.

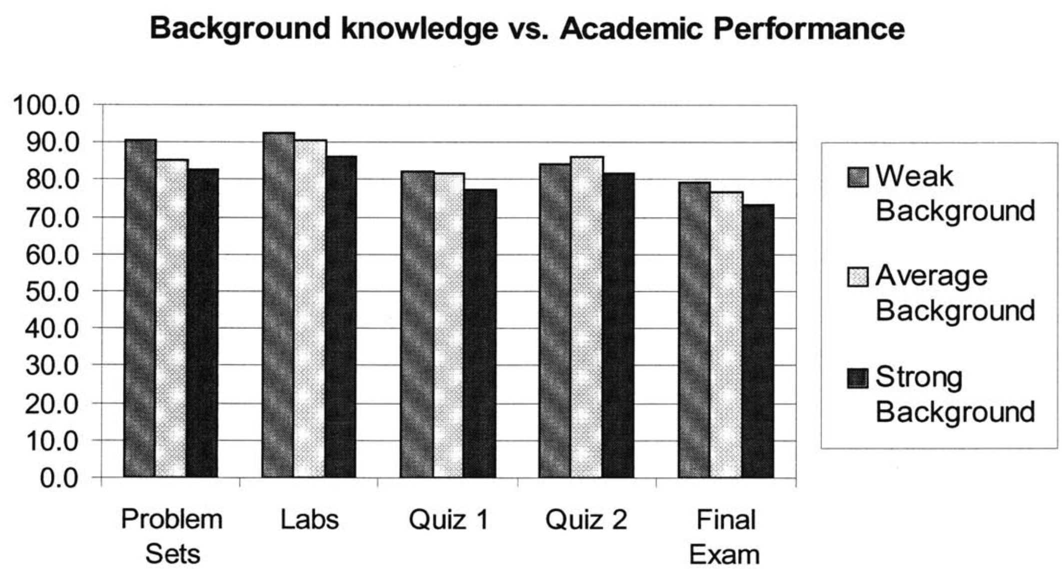


Figure 3-7: Academic Performance by Background

However, contrary to expectation, figure 3-7 shows that the students with lower background consistently out performed the students with higher background knowledge, if only slightly. This anomaly might be explained by noting that the correlation between the percentage of students spending higher than average time solving problem sets is very negatively high with relation to the students with low background knowledge(Correlation Coefficient $\rho = -0.92$). The time spent studying and solving problem sets is indirectly proportional to the amount of student background knowledge. This indicates that students with less background spent longer amounts of time studying and trying to solve the problems sets, thus reinforcing their newly acquired knowledge and adding more.

3.3.5 Conclusions

The researchers conclude that students with Learning Styles strongly matched to the instructor's teaching style are generally more satisfied with the instructor and with the subject as a whole. In addition, these students achieve higher academic performance than their peers. Dunn, of the Dunn and Dunn learning styles model, asserted that a match between student learning styles and teacher's learning styles may lead to improved student attitude and higher academic achievement[7]. Larkin-Hein and Budny [21] believed that the learning style assessment tool used was not as critical as the actual assessment of the learning style. Results clearly show this to be true.

Practiced instructors learn to customize their teaching style to the dominant learning style of the class. The importance of this is made clear from studies showing that students evaluate good teaching characteristics and the quality of instruction [1, 9, 10, 17].

Despite knowledge of what characteristics are preferred by each learning style, it is still not known how to specifically tailor class activities to maximize academic achievement. Students with multiple strong or weak learning styles are more difficult to target and specific activities meant to target a learning style do not always accomplish the goal due to differences in grading, implementation, instruction and content.

Students' background knowledge may affect performance either positively or negatively depending on student habits, however, results show a tendency for better performance from students with a weaker background, perhaps because they work harder to catch up to the material.

Student's background fields affect their performance significantly due to prior training, application areas and educational background. Research shows that students' preferred teaching approaches are influenced by contextual factors such as the discipline they study[10, 14]. Students tend to study in academic disciplines that suit their approach to learning and personal characteristics. In addition, they adapt in the course of their studies to the discipline's specific modes of thinking and learning[8, 22].

Chapter 4

Studies on Customized Lectures

4.1 Introduction

Ever since people began educating each other, teaching has followed a very traditional and unwavering scheme. Despite the advances in every other aspect of human life, this aspect has remained quite static until very recently. With the many approaches to a topic that are available today, and with the presence of vast information databases and low costs in computer technology, it seemed only natural that the next step in education would involve computers as well. However, there exists a crucial link between these information databases and their effective use in teaching that is still missing.

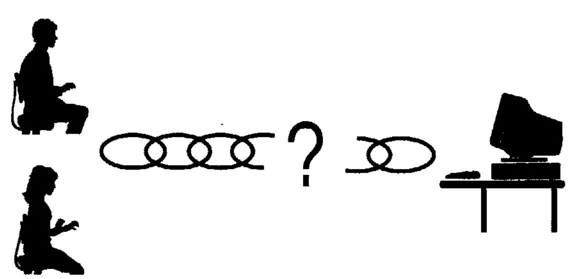


Figure 4-1: Missing Link in Web-based Education

This gap can only be reduced if an effective method of delivering this content can be obtained without the usual side effects of information overload.

In I-fluids, educators are focusing on involving Hydrodynamics experts in the assimilation of their individual content into a more coherent and effective source.

4.2 The Current Study

Consider a smaller and more limited instance of the above described problem. The aim is to determine the path through a set of content that best meets specific user criteria, focusing specifically on learning style, background and field of specialization.

Some experiments were performed on a graduate level hydrodynamics course focusing on a specific topic: 'lifting surfaces'. The objective was to determine how different approaches to teaching impact the learning of students with different characteristics.

Students were presented with three different presentations of the same lecture, with the same concepts and learning objectives for all three expected. They were then asked to chose their most preferred lecture. Their choice was then correlated to their already measured attributes to determine whether one can accurately leverage content effectively according to a student's attributes.

It is anticipated that students who have strong logical, judgmental behaviors(mainly theorists) will lean more towards the mathematical proof approach, while the more creative students(mainly reflectors) will prefer the learning by intuitive approach, in which they are given time to reflect upon the ideas therein. Students who have neither strong logical or strong creative preferences but who prefer to actively learn through experimentation will prefer the experimental approach with simulations.

In addition, a study on student academic improvement was attempted as a result of presenting lectures specialized to each student's learning style. This was done by asking students three questions that corresponded to the lecture types presented. The question types were conceptual, analytical and design.

In conclusion, knowing how best to navigate through a content set given a certain group of students with similar characteristics gives some guidelines on leveraging content to provide more effective teaching. These guidelines, if in turn, applied to Web-based learning programs, can augment a classroom experience significantly by helping weaker students get up to speed and keeping the stronger students interested.

It can also give the instructor more freedom to cover material that may be of more interest to the class or field of expertise rather than dwelling over the basics.

4.2.1 Method

The same students were used in this experiment as in Chapter Three. The following approach was employed. One lecture presenting some basic concepts of 'lifting surfaces' was presented to students in three different styles. The first focused on a logical, step-by-step mathematical derivation concepts, following a vertical sequential presentation. The second lecture presented an intuitive discussion of the concept and attempted to guide the students in making their own assumptions and conclusions. The third method described an experiment designed to demonstrate the concepts physically and included several simulations and videos from which students could actually view the processes that display concepts and principles. The full lectures are shown and their design explained in the following section.

The students were already tested for their learning styles, their proficiency in background knowledge and their undergraduate field. The students were asked to read all three lecture and to choose the lecture presentation most preferred.

4.2.2 Development Approach

The following sections explain the approach taken for designing each lecture. All lectures were meant to present the same set of concepts using different approaches. These concepts were summarized by:

- Lift in potential flow
- Circulation
- Kutta condition

- Kutta-Joukowsky Theorem

The three lectures were meant to target Theorists, Reflectors and Pragmatists. Appendix B shows each lecture in full detail.

Activists were not targeted as they generally prefer being involved in a project, experiments and problems. They enjoy short here-and-now activities such as educational games, competitive teamwork tasks and application exercises. Due to time constraints and examination schedules, applications such as on-line labs were not designed or created. In an attempt to simulate an experiment, some Activist features were included in the experimental lecture and the results observed to determine the effect.

Lecture A - Theoretical

The approach for this lecture was theoretical and meant to target mainly Theorists. The designer aimed to present the material in a logical step-by-step manner, using rigorous analysis methods. Beginning from first principles, each concept was to be proven mathematically, where every step taken was a result of the previous step, giving a water-tight argument for each theory. In this vertical, logical way, theorists are expected to learn best.

Lecture B - Intuitive

This lecture was meant mainly for Reflectors. The design for this lecture was based on an intuitive understanding of the physical world and deducing the concepts from reflecting on facts. Students were encouraged to ponder over activities observed, stand back from material, assimilate the information, and come to a conclusion. Material was reviewed to reinforce what was learned. Multiple figures were included to better demonstrate ideas.

Lecture Preference	*Student Preference Percentage*
Theoretical	15.4
Intuitive	42.3
Experimental	34.6
None	7.7

Table 4.1: Student Lecture Preference Percentages

Lecture C - Experimental

The approach to this lecture was through observation of experiments aimed at targeting Pragmatists. The basic ideas were first explained, then an experiment described in detail, with various comparisons between real life situations and the ideal theoretical situations. Many movies and figures were included in this approach, to demonstrate the experimental process and give the impression that an experiment was being performed. From the experimental data, observations were made and the concepts concluded as a result of explaining data characteristics.

4.2.3 Results and Discussion

The first question to answer is: Do we know how to write a lecture to target a particular learning style? Three lectures were written with the aim of targeting Theorists, Reflectors and Pragmatists.

Table 4.1 shows the percentage of students preferring each lecture type.

Note that the intuitive lecture was the most preferred lecture with the experimental lecture following closely.

Results show that approximately fifty percent of strong activists, pragmatists and reflectors preferred the intuitive lecture, while the majority of theorists preferred the experimental lecture. These results are unexpected, given the hypothesis that strong theorists would prefer a more theoretical lecture while strong pragmatists and activist would prefer the experimental lecture. However, studies have shown that students favor an approach that they have only seldom or even never experience, whereas they experience much less liking for the teaching approach that they mainly experience

[13].

Figure 4-2 shows that of those students choosing the theoretical lecture, the all were strong Reflectors and Theorists. According to Honey and Mumford [27], the most common combination of learning styles are Reflector/Theorist with an inter-correlation index of $\rho = 0.71$. Therefore these results are consistent with what is known.

Of students choosing the intuitive approach, 78 percent were strong reflectors, indicating that this approach successfully targeted Reflectors. Notice that all other learning styles are of equal value.

Surprisingly, students choosing the experimental lecture were mostly Theoretical with Reflectors following. One reason may be that students generally prefer a teaching approach dissimilar to their learning style if they are strong learners in one style. Evidently, this lecture did not successfully target either Activists or Pragmatists.

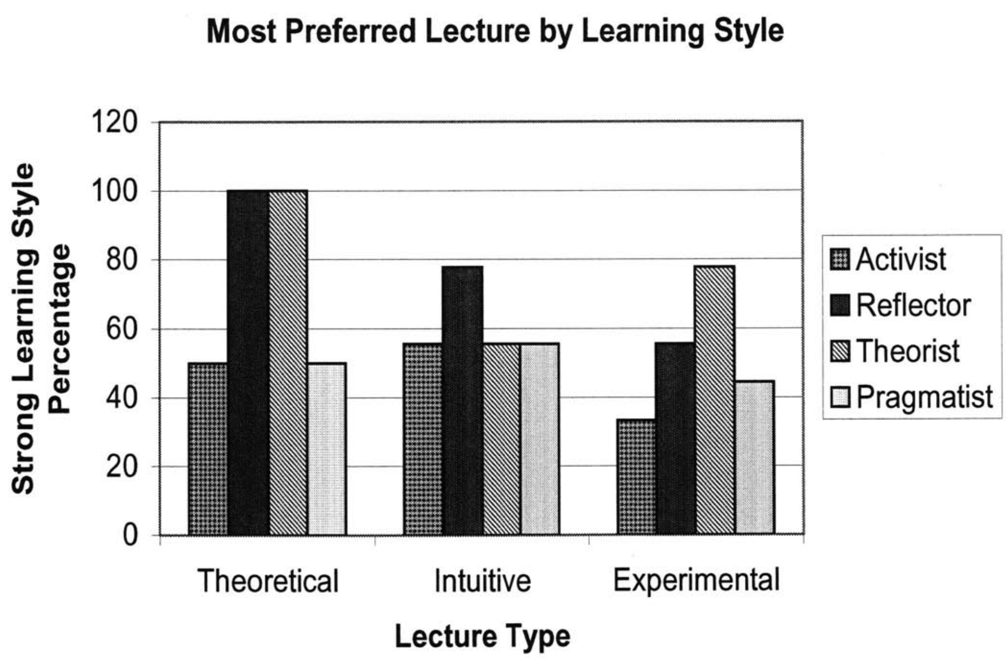


Figure 4-2: Most Preferred Lecture vs. Strong Learning Style

Figure 4-3 shows the relationship between lecture type chosen and the types of problems presented in problem sets. Results show students preferring the theoretical lectures performed highest on analytical problems while students preferring the experimental lecture excelled in conceptual problems. Design problems achieved lowest performance in comparison to other types. This is likely due to a minimal design component in the class in addition to the lack of lectures targeted towards practical design work.

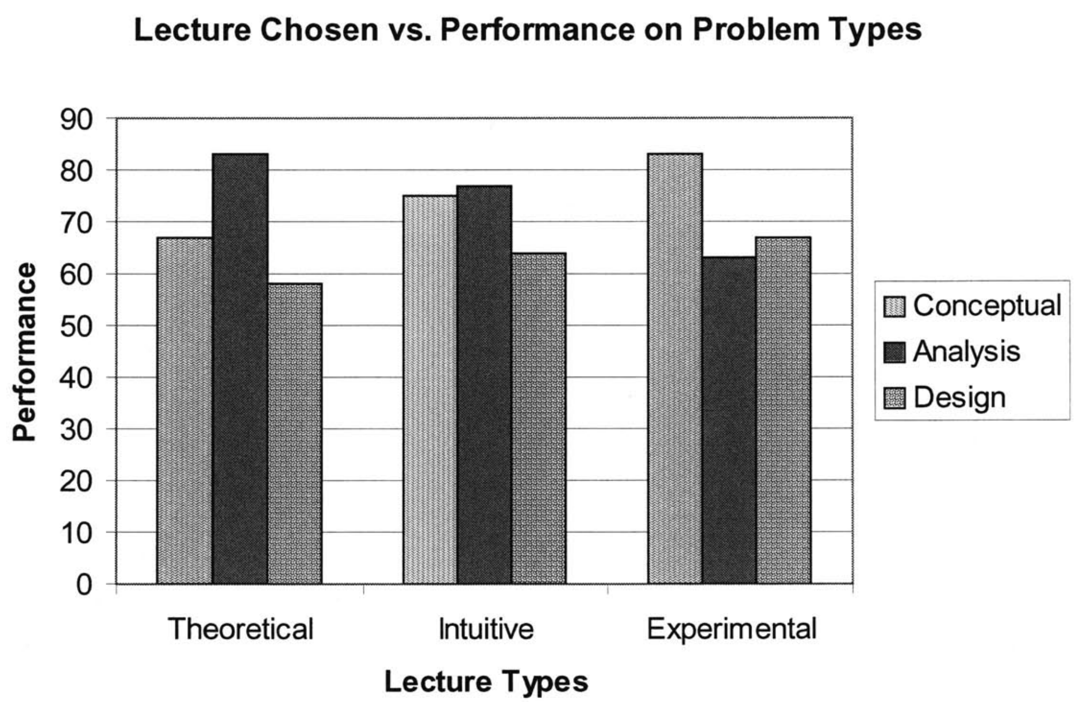


Figure 4-3: Lecture Chosen vs. Performance on Problem Types

Figure 4-4 shows the percent improvement in academic performance of students before and after choosing their most preferred lecture. The evaluation in improvement was rather poorly measured, as a very limited sample of responses was available for study. The only noticeable improvement evident from this figure is the 14 percent improvement of Theorists in their analysis skills.

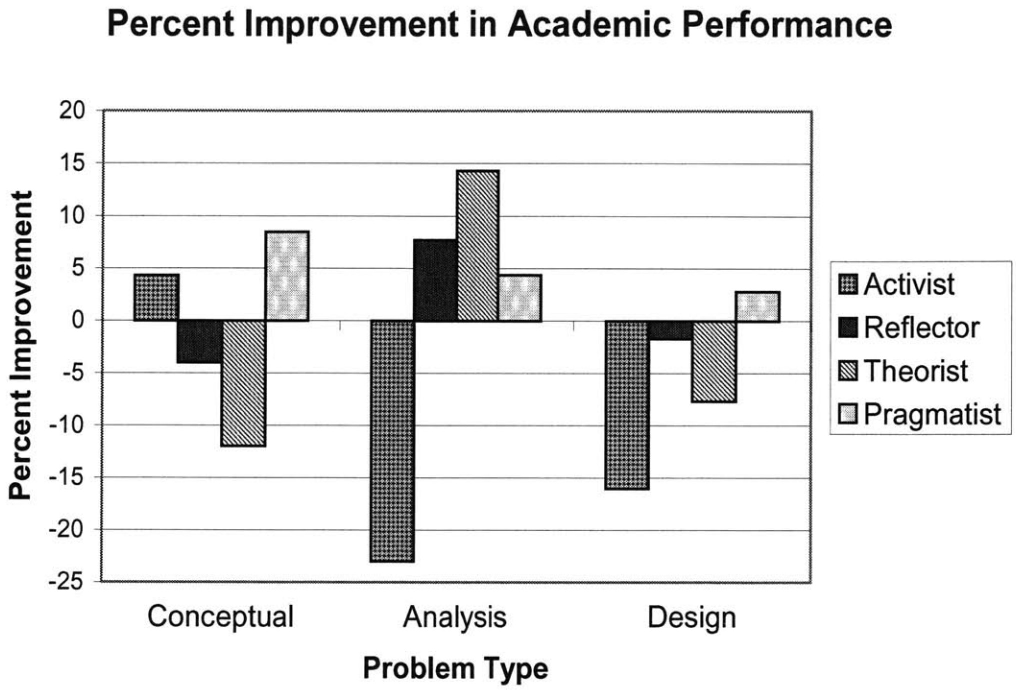


Figure 4-4: Percent Improvement in Academic Performance

4.2.4 Conclusions

In conclusion, designing a lecture to target a specific learning style must be undertaken by domain experts with an in-depth understanding of the subject and how each aspect affects education. The designer in this case had only a basic knowledge of the material and virtually non-existent teaching experience. Most likely, to achieve a more successful result in this type of a study, an experienced instructor would have to assist in the creation of tailored lectures.

Chapter 5

A Conceptual Method for Customized Dynamic Delivery Using Effective Teaching Techniques

5.1 Introduction

In this chapter a method of leveraging extensive content for 'specialized' educational use effectively will be addressed. The key is to have the material dynamically customized and delivered to an individual student based on (prior and continually improved) knowledge of the individual's attributes, abilities, learning styles, background, experience and culture. The aim is to develop an approach that captures what a domain expert and good teacher would do. In the following chapter, one such method is outlined and explained. Through strategic indexing and preparation of a limited amount of material beforehand, we will show that it is possible to achieve a certain level of success in customizing information to a student's needs and delivering the content dynamically as the user's attributes and skill levels change.

5.1.1 Background

Both educators and students today acknowledge the fact that we are awash with information and some are constantly seeking more effective and efficient ways to distinguish data, information and knowledge. Efforts are constantly being made to encourage students to approach education from this point of view and to develop these skills that will enable them to absorb the knowledge that they will find most useful to themselves. In aiding this cause, many have turned to computer aided instruction and the use of interactive multimedia to aid the learning process. However, the implication that the user stands a better chance of becoming actively engaged in a subject and thereby improves his/her net learning simply because he/she must interact with the technology does not hold [?].

Montgomery Woods and co-workers assessed a variety of design and instructional techniques used in 22 commercially available CD-ROM packages (educational, stories and games) to examine a broad cross section of material outside of academia in order to identify effective devices useful for the design of more effective courseware. In conclusion, they suggested that the concept of self-contained courseware packages shifts the responsibility of learning more firmly onto the student. As a result, the focus of the design must be on the student [33]. This is not to say that the role of the teacher is now redundant, but that attempts should be made to include characteristics of effective teaching in any self-contained courseware package. There remains an ever-present demand for a human-guide, facilitator and moderator of the learning process as well as a source of additional information, experience and insight.

5.1.2 Objective

The objective of this project is to determine a structure for a dynamically deliverable educational module that can be customized to an individual user's characteristics. Many educational modules today are static, targeting a general group of students with little regard to their learning styles, background, area of interest or learning objectives. The methodology in this module aims to develop a more versatile and dynamic content delivery scheme that takes the above-mentioned factors into account and assumes a different content for each user. In following sections, we will describe the approach taken to index the content by topic rather than by keyword, and the algorithms used in attempting to deliver material suited to an individual's needs each time the module is accessed.

5.2 Project Requirements

The process initially envisioned for these modules are as follows. The end user must be capable of starting the module, taking a test, choosing a subject, time frame, difficulty level, etc ... The user will then see the most suitable information following his personal criteria and a general outline of the topic chosen. The specific content will be dynamically selected and custom delivered. As the student learns and his needs change, the content, amount, concentration and method of delivery will change as well.

Three different facets of the project are assigned specifications that should leave us with a more coherent end result. These facets are:

1. Application
2. Information
3. Technology

5.2.1 Application

This feature addresses the usage and application of the module. The following list gives a brief description of each requirement.

- Commonality: defining the best way for basic units to be shared among each other and at different levels.
- Modularity: understanding the efficacy of different - levels and degrees of modularity - Strategies of defining such grouping

- Scalability: Ability of modifying a common concept to conform to different fields, cultures, etc but avoiding redundancy
- Robustness: Managing subject-changes as a result of new information, interest and scope.
- Dependency: Linkages, dependencies and prerequisites must be preserved and captured in the different and often unpredictable pathways through the content.
- Manageability: Allowing additions and retractions of information to and from the database without affecting the flow of information.
- Flexibility: Modulation or filtering of content based on given static/dynamic attributes.

5.2.2 Information

This feature focuses on handling the content database. It can be subdivided into the following:

1. Information access: Access of information must be simple and direct. We have devised an indexing method for the content. The particulars of the indexing will be covered later on in the presentation. Using this indexing method will simplify access to information and help keep it organized.
2. Usage patterns: Usage will depend on the user and his needs criteria.
3. Database management: The management of the database will also be handled through the indexing method.

5.2.3 Technology

The technology is the final facet of the implementation. The final success of the project depends on how well the ideas are implemented using existing or developing technology.

1. Technical specifications: Provide the ability to define, create, read, save, update, and delete and maintain persistent application data
2. Application interface: Hide the design, implementation and location of data and functions.
3. Development environment: User oriented, point-and-click interface.
4. Security: Allow capability of saving user information securely on user-side or application-side. Provide user option to allow instructor access to progress.

5.3 Approach

Good design is achieved through a user-centered approach, where planning occurs while building in an iterative, solutions-based process. A common set of expectations must exist for the users, instructors and developers so that the end product is successful. Both the problems and solutions must be viewed from the points-of-view of the user and the instructor so that complexity is minimized and maximum effectiveness is achieved. The design stage is divided into three iterative and evolutionary stages:

- Conceptual design
- Logical design
- Physical design

5.3.1 Conceptual Design

This step shows the big picture of the project avoiding details about implementation and technology. At the conceptual design stage, needs are identified and an understanding of what the user does and requires is achieved.

Consider the following components of the module:

- User: The 'User' is the person learning from the module.

- Application: The application is the interface between the user and the content. Here resides the algorithm for content retrieval depending on the user attributes.
- Database: The database contains a large quantity of material such as lecture notes, movies and exercises that are used to help the user learn.

Diagram 5-1 may help to clarify the concept.

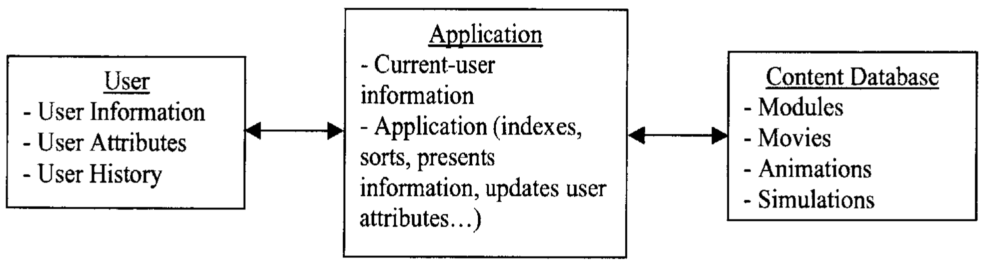


Figure 5-1: Module Components - Conceptual Design

5.3.2 Logical Design

In logical design the organization of the solution is determined and the communication of its elements are defined. The structure of each element in the solution is outlined and details are considered. The solution is viewed from the perspective of the project team and the solution is defined as a set of cooperative services.

Module Design

1. Modularize and sequence information.
2. Subdivide material into the smallest logical atoms possible.
3. Assigned a set of attributes to each atom. Each of these will correlate to the user's attributes.
4. Attributes are then assigned a rank that reflects the degree of relevance of each attribute to its attached atom.

The development of this indexing and delivery scheme was subdivided into two major stages. The first stage involved the preparation of the material prior to its use. The next stage was to develop an effective mode of delivery.

In the first stage, a topic of interest was chosen and a set of data relating to that topic was assimilated for testing. The topic chosen was 'Kelvin's theorem'. One approach to teaching this concept is shown in the diagram below.

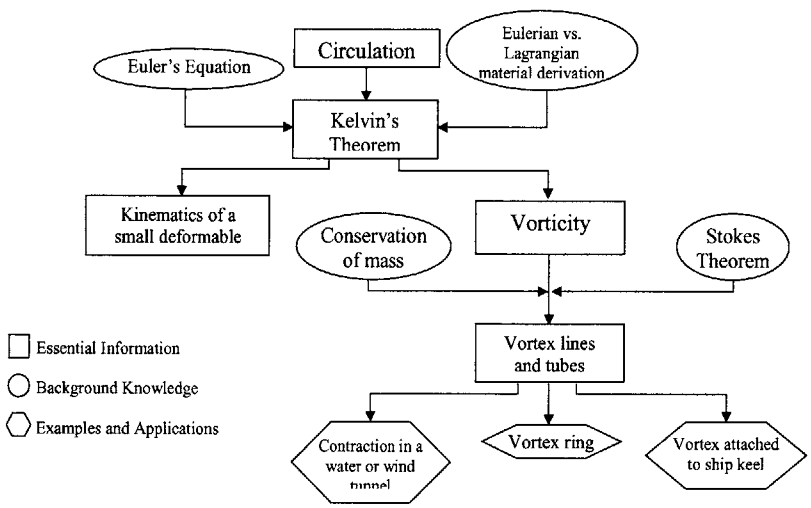


Figure 5-2: Kelvin's Theorem Sequence Map

However, a certain logical succession exists where one topic must be taught before another. These logical steps are as follows:

1. Circulation

2. Kelvin's Theorem

3. Small Body Deformation

4. Vorticity

5. Vortex Lines and Tubes

The examples can be presented at any point relating to the material. In this case, most examples are given at the end of the data set. This data set presents only a very

Learning Styles			
Activist	Reflector	Theorist	Pragmatist

Table 5.1: Learning Styles Traits

Background		
Calculus Differential Equations	Vector Analysis Complex Arithmetic	Undergraduate Fluid Mechanics Dynamics

Table 5.2: Background Traits

small topic and is thus called an element. The final module will eventually consist of many such elements that are linked together in a similar manner.

This data was a compilation of information from several published books relating to the chosen subject. The information was then subdivided into the smallest logical pieces possible; atoms. That is, the information at each stage was broken down into smaller pieces for indexing.

Next, a set of attributes relating to both the material and the user was chosen. Tables 5.1 to 5.6 of attributes shows a list of possible traits relating to these attributes.

The attributes chosen for testing the method were Learning style and Difficulty. Only Theorist and Reflector traits from the learning styles were used. The same traits were used for both the user and the atoms. All the user traits are placed in a *User-State-Variable*(USV); a dynamic vector that is modified as new material is learned. The traits relating to the atoms are placed in a static vector: the atom vector.

Each trait in the atom vector is then assigned a ranking or a value that rates the atom's relevance to this trait. For example, if an atom requires strong knowledge of background material, the background trait is given a value of 8 on a scale of one to

Difficulty		
Basic	Intermediate	Advanced

Table 5.3: Difficulty Traits

Application Area	
Naval Architecture and Marine Engineering	Mechanical Engineering
Aero/Astro Engineering	Ocean Engineering
Physical Oceanography	Civil Engineering
Electrical Engineering	Materials Science

Table 5.4: Application Area Traits

Alertness/Intelligence		
Dull	Average	Sharp

Table 5.5: Alertness/Intelligence Traits

ten.

The traits are ranked similarly in the user-state-variable, however, the ranks are with respect to the user's knowledge. As the user learns more, it is only natural that his user-state-variable would be updated.

So each atom will then have a *tag* attaching it's vector to it. This will allow for quick indexing and dynamic sorting of the material.

Module Delivery

1. Acquisition of knowledge: The user is tested to establish the ranking of his attributes. The ranks of the user attributes are variable depending on each step therefore it is a user state variable. Note that the user attributes and the atom attributes are the same. We try to investigate cognitive, affective and motivational aspects of the student. - A test of the user's background determines the cognitive measure. What to teach? - A test of the user's learning

History	
Taken/Done	Not Taken/Not Done

Table 5.6: History Traits

style determines affective and motivational measures. How to teach?

2. Determining methodology

    - A back-to-front lock-step method is used to determine the starting point of the user path.
    - The user-state-variable ranks are compared to the element ranks and the best-correlated atom(s) is/are chosen.
    - The atom is imparted.
    - The user-state-variable is updated and the rank-indexing continues.

The next step, is determining a method of linking these atoms into an articulate and rational arrangement that will effectively relay the desired concepts to the user. This is done through pointers that are included in the atom's tag. Each atom will have a set of pointers that direct the user to a set of the next most pertinent atoms. These pointers redirect the user from the current atom to the next most relevant atoms after the current one is imparted. The pointers can point to multiple atoms, atom subsets, or entire elements.

All pointers are bi-directional, so if atom A points to atom B, then atom B also points to atom A. At the onset of the path, all pointers are equally weighted. However, if an atom is imparted, its weight is decreased and thus becomes less likely to be chosen next time, until all other possibilities are exhausted. Once all atoms have been visited, the same atom can be conveyed again if it needs to be reviewed by the user.

Ex:

An indexed and 'atomized' example of the circulation subset is shown in Appendix C.

Using the Frobenius norm,

$$F = \Sigma_i |X_i - Y_i| \tag{5.1}$$

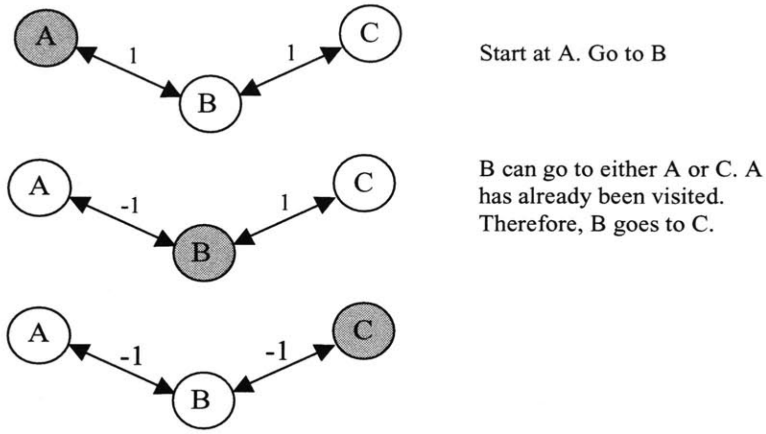


Figure 5-3: Diagram of Pointer Method

where X_i is the user-state-variable vector and Y_i is the atom vector for each attribute i, the user-state-variable values are compared to each of the atom values pointed to by the current atom to find the shortest distance to the next atom. This directs the user to the atom that matches his user-state-variable best.

Example

Consider a user A with the user-state-variable in figure 5-4:

User A	Theorist	5
	Reflector	8
	Background	5

Figure 5-4: Initial user-state-variable for User A

This indicates that user A is a moderate theorist, but a strong reflector, with an average background on a scale of 1-10.

Note that Appendix C shows the full indexing of the material shown in figure 1.

Referring to Appendix C, let user A's path begins at 'A [Circulation]'. The next atom, is the one that A [Circulation] points to: B [Circulation] soothe user has no choice but to go to that atom. Next, 'B [Circulation]' points to 'C [Circulation]', 'E [Circulation]', 'F [Circulation]' and 'D [Background]'. Using the Frobenius norm, the atom that matches user A's user-state-variable best is determined(figure 5-5).

USER	C [Circulation]	E [Circulation]	F [Circulation]	D [Background]
5	6	8	4	8
8	8	6	9	7
5	4	6	4	4
F	**2**	**6**	**3**	**5**

Figure 5-5: Atom Matching Process

Therefore the distance '2' to 'C [Circulation]' is the shortest and is thus the next atom imparted. Next, 'C [Circulation]' points to 'D [Circulation]' and 'E [Circulation]'(figure 5-6);

USER	D [Circulation]	E [Circulation]
5	8	8
8	7	6
5	4	6
F	**5**	**6**

Figure 5-6: Atom Matching Process

Atom 'D [Circulation]' is imparted. D points to 'F [Circulation]' and 'E [Circulation]'(figure 5-7);

USER	F [Circulation]	E [Circulation]
5	4	8
8	9	6
5	4	6
F	**3**	**6**

Figure 5-7: Atom Matching Process

So F [Circulation] is given. F [Circulation] points back to D [Circulation] which now points to E [Circulation]. E [Circulation] points to atoms in the next element.

The complete path for User A through these elements is shown in figure 5-8.

Next, consider a User B whose user-state-variable is shown in figure 5-9:

Circulation	A → B → C → D → F → E →
Kelvin's Theorem	B → C → E → G →
Small Body Deformation	A → B → C → I → J →
Vorticity	A → B → C → D → F →
Vortex Lines and Tubes	A → C → D → E → F → G → F →
Examples	C

Figure 5-8: Complete Atom Path for User A

User B		
	Theorist	9
	Reflector	3
	Background	2

Figure 5-9: Initial user-state-variable for User B

This indicates that user B is a strong theorist, but a weak reflector, with a poor or basic background on a scale of 1-10.

The same procedure as for User A is followed to determine the path for User B. The final path is shown in figure 5-10:

Circulation	A → B → D [Background] → E →
Kelvin's Theorem	A → A [Background] → B [Background] → B → F →
Small Body Deformation	A → B → C → H → I →
Vorticity	A → B → C → E → F → H → I → J →
Vortex Lines and Tubes	A → B → C → D → E → F → G → H → I
Examples	

Figure 5-10: Complete Atom Path for User B

Note that user B started out with a background value of 2. As the lesson progressed, the value was changed to a 4 after several background atoms were imparted. So the final tag appears in figure 5-11 :

Observe that the paths that user A and user B follow are quite different depending on their attributes. The reflector gets more examples and less theory, while the theorist doesn't get examples but substantial background help and more theory than

Attribute	Initial Value	Final Value
Theorist	9	9
Reflector	3	3
Background	2	4

Figure 5-11: Initial and Adjusted Atom

the reflector.

5.3.3 Physical Design

The physical design is a services-based approach that applies real-world technology constraints and implementation considerations to the design. The solution is viewed from the perspective of the designers. This is where the services and technologies of the solution are defined.

5.4 Incorporating Effective Teaching Characteristics

1. Richness of Content/Knowledge

   This element is inherently included in the module by simply assimilating the content database. It can be expanded and improved depending on what features the designer wishes to include. One idea in store for the future is the availability of more software application capabilities that will help in modelling ideas that the user wishes to visualize. In addition, the creation of educational games is being put forward, as another method of targeting the user who enjoys learning by activity; trial and error.

2. Needs Anticipation

   Consider a student X with the following user background and reflector attributes (among others).

User X	Background	2
	Reflector	3
	--------	-

Figure 5-12: Attributes for User **X**

The student has an average background and is a strong reflector on a scale of zero to three. Therefore, with respect to the course, his background knowledge is the same as most of his classmates but his preferred learning style is reading and analyzing data.

The element shown in figure 5-13 gives a representation of all parts of a chosen subject in the database at any time. Each idea is represented from different angles depending on learning styles. These can later on be developed to include different difficulty levels, application areas, etc

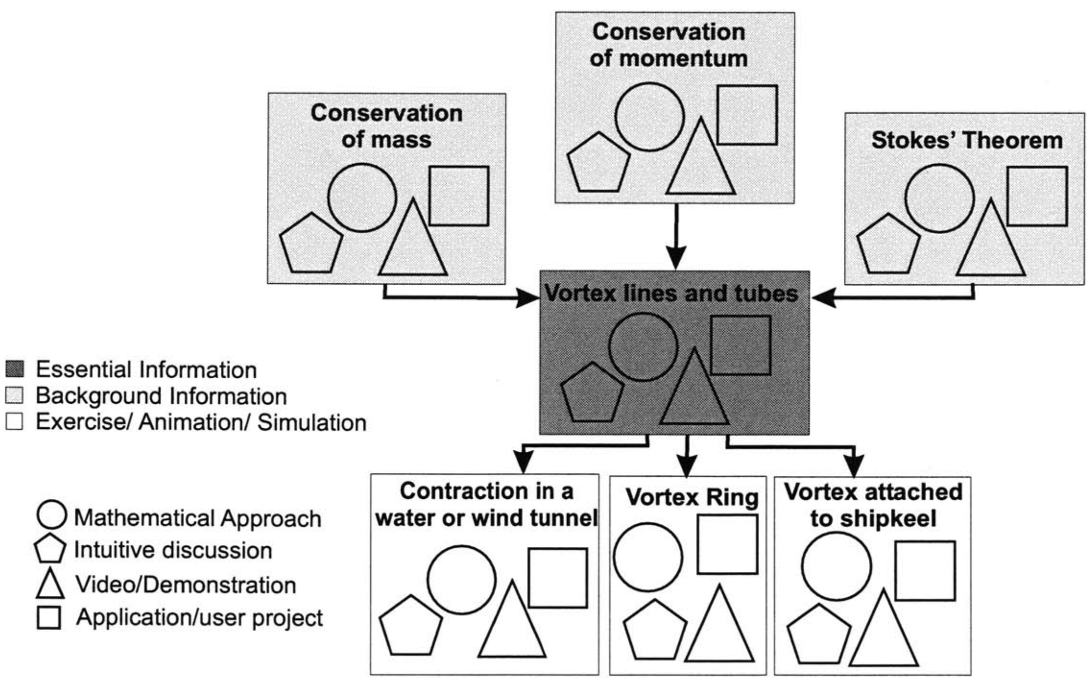


Figure 5-13: Diagram of Complete Element

Given the user's attributes, where his background is moderate, he is taught only some background information that he requires; Stokes' Theorem. The essential information is then imparted using the approach that matches his learning style best. This information is then reinforced with two examples focusing on the elements that cater to the reflector learning style. Thus what the user actually sees is shown below.

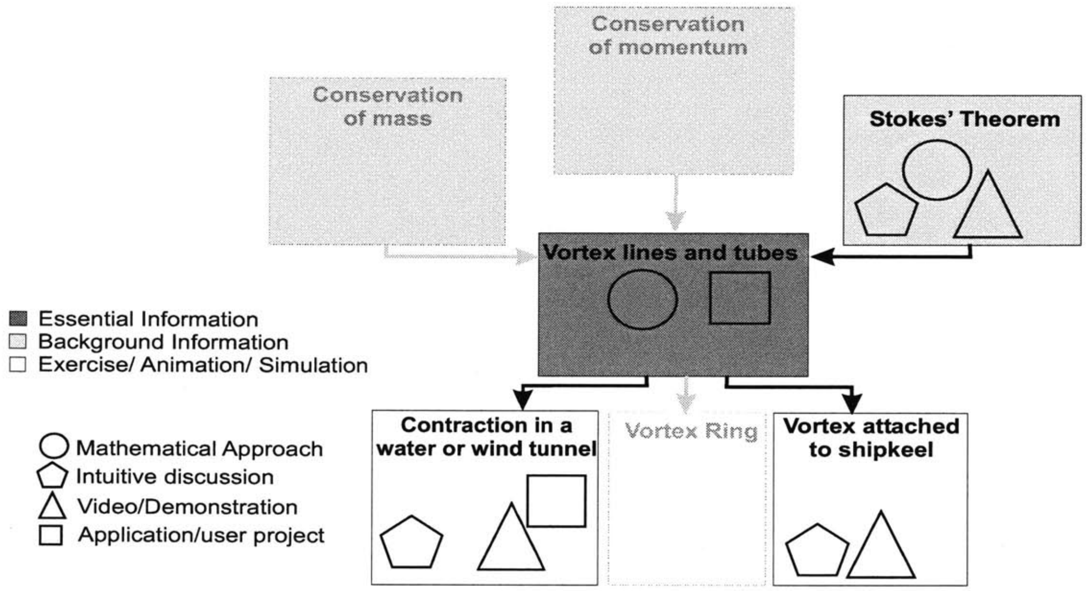


Figure 5-14: Element Components Presented to User X

Therefore, depending on the user's attributes, his/her learning needs are anticipated and put forth, in an effort to reduce redundancy and yet provide the necessary background material for the present concept.

3. Customization

Consider two students X and Y with the following user-state-variable. These students have just begun this module while both taking an introductory fluids course. The only value their user-state-variable contains so far is the number of the course they are both attending.

The same content for all is initially available in the database. This content is static and does not change. Only the selected elements presented to the users

User X	Background	-
	Reflector	-
	Class attending	13.021

User Y	Background	-
	Reflector	-
	Class attending	13.021

Figure 5-15: Partially Filled User State Variables

change.

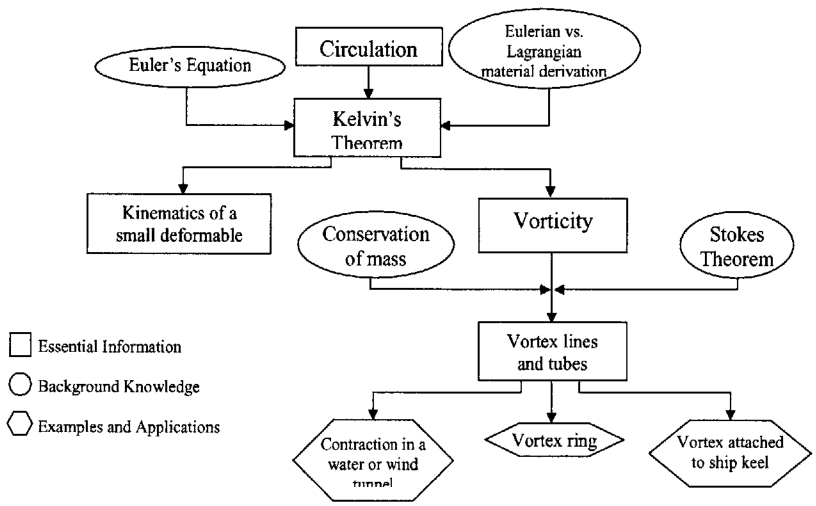


Figure 5-16: Information Sequence Map

However, each student is evaluated and assigned his/her respective attribute ranks. Thus their respective user-state-variables are now modified and look like the following:

User X	Background	3
	Reflector	2
	Class attending	13.021

User Y	Background	1
	Reflector	3
	Class attending	13.021

Figure 5-17: Customized User State Variables

As a result, each user is presented the information best suited to his/her style. This avoids information overload and reduces confusion while targeting the user's optimal learning style and yielding maximum results for each user.

4. Dynamic Delivery

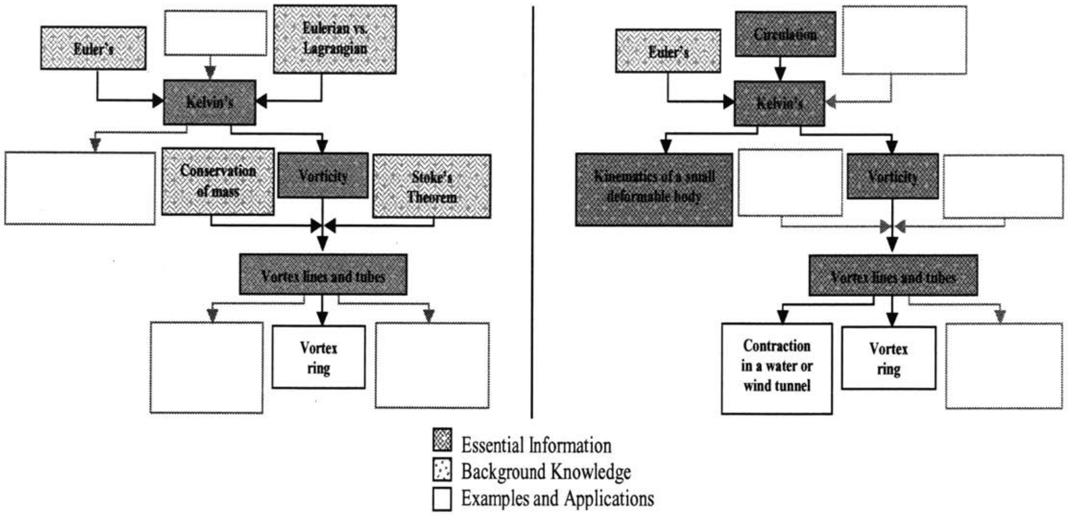


Figure 5-18: Customized User Paths Through Material

Suppose two students, once again X and Y, have taken a background test and were ranked with the same background value (figure 5-19).

User X	Fluids Background	1
	------	-
	------	-

User Y	Fluids Background	1
	------	-
	------	-

Figure 5-19: Initial Background Ranking

Assuming that all other attributes of these users are similar, they begin learning the same information, a revision of basic fluid mechanics. After some time, they are both given a five question quiz. It happens that student X has forgotten some basic fluids principles, or maybe has a learning style differing from that of student Y. Student Y scores 4/5 while student X scores only 2/5. The nature of the questions will provide some guidance as to where the problem may be. Therefore, through this assessment, the user-state-variable for each user will be updated. Perhaps user X's learning style will be slightly modified. User Y's fluid background ranking will now increase since he has successfully completed the background element(figure 5-20). And so on.

User X	Fluids Background	1		User Y	Fluids Background	2
	----	.			----	.
	----	.			----	.

Figure 5-20: Adjusted Background Ranking

Question 1	
a incorrect	Calculus weakness
b correct	Move to higher difficulty
c incorrect	Fluids weakness
d incorrect	Calculation error - try another question
e incorrect	incorrect Misunderstood theory

Table 5.7: Sample Assessment Question Template

It is clear that in the next element presented, user X will receive some additional background support while user Y will be able to move on a little quicker as he/she has had sufficient revision.

5. Student Assessment

   Student assessments are generally in the form of quizzes or problem to solve. They can also be more subtle in that a record of student speed through the module, elements requested for review, or type and number of exercises chosen can be keep throughout the module. The most common assessment however, would come in the form of a questionnaire presented at the end of each element to verify whether the user has achieved all the learning tasks that were presented at the beginning of the module. The questions can be of different format.

   One example is a list of multiple-choice answers, where each incorrect answer has a specific underlying error that indicates where the user is having difficulty.

   Another option is to have a list of difficulties that the user has encountered and have him choose one or several, in which case, the module backtracks over some of these specific areas and uses a different approach.

5.5 Example: Kelvin's theorem

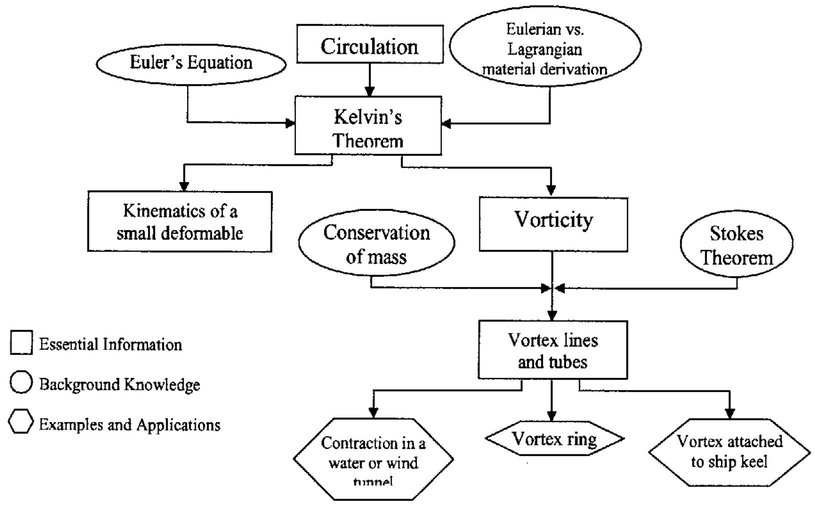


Figure 5-21: Kelvin's Theorem Sequence Map

Every box in diagram 5-21 is an element. Within the elements are different methods of presentation with various applications, exercises, simulations and demos. The elements are subdivided into progressively smaller pieces and these are the atoms that will be tagged with the attributes.

Let 'Box I' be the 'Circulation' element. Within this Box I are 6 'atoms' let's say. These are atoms 'A' through 'F'. To these atoms a list of attributes is attached and ranked. Shown below is a simple example of only one attribute; the learning style attribute.

Let the ranking scale for the element attributes be as follows:

1. Slight relevance

2. Moderately relevant

3. Highly relevant

By comparing the user-state-variable ranks to the ranks of the element attributes, the optimal matches for this user-state are elements A and C. Therefore these will

Atom A	Activist	0
	Theorist	2
	Reflector	3
	Pragmatist	1

Atom B	Activist	0
	Theorist	3
	Reflector	2
	Pragmatist	0

Atom C	Activist	3
	Theorist	1
	Reflector	2
	Pragmatist	2

Atom D	Activist	3
	Theorist	2
	Reflector	1
	Pragmatist	3

Atom E	Activist	2
	Theorist	1
	Reflector	1
	Pragmatist	3

Atom F	Activist	3
	Theorist	0
	Reflector	2
	Pragmatist	3

Figure 5-22: Ranked Atoms

be presented first. The user-state-variable will then be re-assigned, the sequence re-evaluated and the next atom presented.

User state variable	Activist	2
	Theorist	2
	Reflector	3
	Pragmatist	2

Figure 5-23: Final User-State-Variable

Note that this method can be expanded to accommodate an atom having many related attributes instead of just one.

Instructional Objectives

Through these modules, there are certain goals that we must achieve with respect to the user. Therefore, apart from the project requirements, there are module requirements that must be considered as well. Each module is divided into elements. Each module must have some instructional objectives that help guide the learning process of the user. Each element of the module must have specific learning tasks. The instructional objectives provide focus for instruction at each module while the specific learning tasks provide activities designed to achieve the intended outcome. The instructional objectives are needed to integrate teaching, learning and assessment; a requirement for successful education. By sharing with a student the intended outcomes of a performance or skill at the beginning of instruction, we provide direction to their learning and provide them a basis for evaluating their own progress and developing self-assessment skills. The instructional objectives must be clearly stated as specific learning outcomes. Some objectives would be:

- Reasoning
- Problem solving
- Performance skills
- Application of learning to 'real-life' situations

Chapter 6

Design issues

6.1 Introduction

Chapter four described a methodology for physically implementing the CDD module, however, results used in chapter four were acquired from a simple paper implementation of the methodology. This chapter describes some of the more practical technical issues that one may encounter in trying to put such a module into operation.

Many design issues arise in the development of such a complex module. Despite a step-by-step approach and a radical simplification if the process

6.2 Stages of Implementation

The process envisioned for constructing the module consists of several modular stages that are linearly linked to each other.

The first stage is the 'atomization' of the material to be accessed. Each document would be accessed by the domain experts, they would have the capability of highlighting what they thought would make a coherent atom. Each atom is represented as a linear combination of sequence/relevance vectors.

For each atom, a tag would appear where the domain experts would fill out the ranks of each attribute, and so on. This process would be extremely lengthy and would require a method of scaling ranks between different domain experts, however it would only be a one time process. In addition, some measures of constancy would be required in which symbols and characters were defined globally throughout the module.

The first two stages are preliminary stages that each document would be subjected to only once. The following stages occur every time a new user is logged onto the system.

Once a user logs onto a system, he/she takes a one time assessment that measures their background knowledge, their learning style, field of interest and learning objectives for the entire course of study. Next the learning objectives for the current session are determined, and a user-state-variable is filled out with the appropriate ranks.

Atoms and user-state-variables are modelled as elements of a vector space. For retrieval, a user query vector (UQV) is obtained from the user-state-variable. With the user query vector available, and a particular destination determined, the matching process begins where all the atoms within a certain element that match the user query vector most closely are obtained. The UQV is matched against each atom vector within a relevance space and a retrieval status value (e.g. cosine coefficient) is calculated that measures similarity of atoms to the query. The Retrieval process returns a list of atoms calculated by retrieval status values within the relevance space. This process is repeated in each sequence plane and for each relevance space.

Once the atoms in each element are chosen, however, they need to be presented in an orderly sequence that delivers a coherent conclusion in the end. The atoms chosen are then rearranged according to a sequencing algorithm.

These are then presented to the user according to his or her preferences. Atoms can be viewed several times and the user has the option to skip a particular atom or set of atoms.

Finally, after each element subset, the users are given an assessment to determine the extent of their acquired knowledge, to update their user query vector with the new attribute ranks, and to determine where in the knowledge plain to move on to, whether to repeat some information, according to what attributes the information should be repeated.

6.3 Evaluating Effectiveness

Determining the effectiveness of a module is a multidimensional task that requires evaluation of every facet. Identified below are three elements that quantify effectiveness.

6.3.1 Quality

The quality of the module must be evaluated by the following measures:

- *Overall Performance*: The overall performance includes the application of ideas, the information content, and technological performance. Application should be evaluated by teaching and development experts, information by domain experts on the topic and finally technology by software development professionals.

- *Coverage*: The coverage should be as complete as possible, however redundant pieces of information that are not presented uniquely should be avoided.

- *Segmentation*: Segmentation covers how the documents are subdivided, how atoms are grouped together, and what atoms form coherent elements.

- *Indexing*: Indexing covers the ranking of both atom attributes and user attributes appropriately. Ranking scales should be consistent and ranks normalized.

- *Query creation and Searching* Determining the query vectors and search algorithms such that results acceptable.

- *Information Retrieval and Presentation*: The retrieval of the atoms and atom subsets and their presentation in a logical sequential order.

- *Completeness and accuracy*: The presentation of each group of atoms resulting in a complete lesson or idea. Accuracy involves the lessons containing key concepts.

- *User-System interaction*: Interaction between the user and the system should be simple and easy to use. The module should have instructions, help areas and should be easily navigable.

- *Educational Assessment*: Resulting pedagogical achievements should be evaluated. Assessment techniques and methods scrutinized for accuracy and dependability.

6.3.2 Cost

Cost to User

The cost to the user consists mainly of:

- Effort involved in learning to use the system

- Effort involved in actual use

Cost to Designer

The costs incurred to the designer are:

- Resources needed

- Effort involved in design and implementation of the module

Cost to Domain Experts

The domain experts make a large investment in the effort involved in the one-time indexing process.

6.3.3 Time

Time considerations for all parties involved include the following:

- User Waiting time vs. Learning time
- Designer Creation time for all inclusive multimedia database
- Domain Experts time to index each atom individually

An in-depth evaluation of the module has not been performed as the module is merely a conceptual element as yet.

6.4 Issues

Some of the most pertinent issues in the implementation of this module are the following:

- Atom are dependent on each other
- Atoms must be presented in a coherent sequence
- Criteria for weighting values
- Relevance space for atoms
- Minimum retrieval with maximum benefit

6.5 Areas for Research

Areas for research are mainly technical with a focus in the following current areas and the methods of linking them together.

- Text Segmentation and Extraction
- Data Ranking
- Query Creation and Optimization
- Dynamic Information Retrieval (IR) Models

- Data Categorization
- Assessment and Evaluation

Chapter 7

Summary

The main question in this thesis is: focusing particularly on graduate education in fluid mechanics, can we find a mechanism that effectively represents, retrieves and delivers fluid mechanics information in a coherent sequence that results in the educational advancement of the user via the WWW?

In trying to determine the answer, following set of questions arose.

1. How are graduate students affected by teaching techniques?
2. In fluid mechanics classes, do graduate students have a preference to different components of the class depending on their learning styles?
3. What student characteristics predominantly impact academic performance?
4. Can such a module be implemented? If so, in what context and with what restrictions?
5. Can the same effective teaching characteristics as those of an in-class instructor be used, and if so, will they still be effective?
6. Can each lecture really be customized to individual users.
7. Will this material be useful as an entity to any one person?
8. Can it be used effectively for educational and informative purposes?

9. Will the time and effort it takes to search through this material far outweigh the benefits?

In response to these questions, it was determined that there is a high correlation between primary teaching style and student learning style; a high correlation between teaching style and course satisfaction and academic performance; and low correlation between secondary instructor's teaching styles and student performance and satisfaction. In addition, it was determined that different course aspects such as labs, problem sets and lectures target different learning styles and student and field affect time spent on problem sets and academic performance of students, however knowledge background does not significantly affect academic performance. Also, different types of problems are preferred by different learning styles, which helps in defining a problem specific to a learning style.

In addition, despite knowing what aspects of a lecture a student may prefer, and what type of course a user with a particular group of attributes may prefer, the improvement and preference is not an entirely predictable science and involves many external factors that relate only to the user. As a result, any module designed should reserve significant freedom in usage for the user.

Technical results showed that in a limited setting, by restricting the number of possible references, a customized dynamically deliverable module produces reasonable results. Additional research is required to determine the scalability, effectiveness and robustness.

7.1 Suggestions for Future Work

Future work relating to this project can branch out in several directions. On the pedagogical front, determining lectures that target specific learning styles or subsets of learning styles requires additional research, determining the extent of material presented for different proficiency levels and designing an architectural framework for a topic of material to follow in terms of amount, sequence, background information and relevance.

On the technical front, extensive research is required in the areas of text segmentation and extraction, data ranking, query creation and optimization, dynamic information retrieval (IR) models, data categorization and assessment and evaluation.

Finally, an evaluation of effectiveness, cost, time and benefit is required to determine the value and benefit of such work against the effort required.

Appendix A

Surveys and Questionnaires

A.1 Mid-Semester Survey

Scale: 1 = Very Poor; 4 = Average; 7 = Excellent

1. What is the overall teaching rating of the primary instructor?
2. What is the overall teaching rating of the second instructor?
3. What is the overall teaching rating of the third instructor?
4. What is the overall rating of the subject?
5. How many average hours were are spent on problem sets per week? (numerical value)

A.2 Learning Styles Questionnaire

Honey and Mumford's Learning Styles Questionnaire (LSQ) has a total of 80 items which you are asked to answer TRUE or FALSE to indicate whether on balance, you agree or disagree.

Many items are behavioral, i.e. they describe an action that someone might or might not be seen to take. Other items probe a preference or belief rather than a manifest behavior.

In common with all questionnaires of this type, the LSQ is designed to discover general trends or tendencies running through a person's behavior and does not place undue significance on any of the items.

This questionnaire is designed to find out your preferred learning style. Over the years, you have probably developed learning 'habits' that help you benefit more from some experiences than from others. Since you are probably unaware of this, this questionnaire will help you pinpoint your learning preferences so that you are in a better position to select learning experiences that suit your style.

There is no time limit to the questionnaire. It will probably take you 10-15 minutes to complete. The accuracy of the results depends on how honest you can be. There are no right or wrong answers.

1. I have strong beliefs about what is right and wrong, good and bad.
2. I often act without considering the possible consequences.
3. I tend to solve problems using a step-by-step approach.
4. I believe that formal procedures and policies restrict people.
5. I have a reputation for saying what I think, simply and directly.
6. I often find that actions based on feelings are as sound as those based on careful thought and analysis.
7. I like the sort of work where I have time for thorough preparation and implementation.
8. I regularly question people about their basic assumptions.
9. What matters most is whether something works in practice.
10. I actively seek out new experiences.
11. When I hear about a new idea or approach I immediately start working out how to apply it in practice.

12. I am keen on self discipline such as watching my diet, taking regular exercise,sticking to a fixed routine, etc.
13. I take pride in doing a thorough job.
14. I get on best with logical, analytical people and less well with spontaneous, 'irrational' people.
15. I take care over the interpretation of data available to me and avoid jumping to conclusions.
16. I like to reach a decision carefully after weighing up many alternatives.
17. I am attracted more to novel, unusual ideas than to practical ones.
18. I do not like disorganized things and prefer to fit things into a coherent pattern.
19. I accept and stick to laid down procedures and policies so long as I regard them as an efficient way of getting the job done.
20. I like to relate my actions to a general principle.
21. In discussions, I like to get straight to the point.
22. I tend to have distant, rather formal relationships with people at work.
23. I thrive on the challenge of tackling something new and different.
24. I enjoy fun-loving, spontaneous people.
25. I pay meticulous attention to detail before coming to a conclusion.
26. I find it difficult to produce ideas on impulse.
27. I believe in coming to the point immediately.
28. I am careful not to jump to conclusions too quickly.
29. I prefer to have as many sources of information as possible - the more data to think over, the better.

30. Flippant people who don't take things seriously enough usually irritate me.
31. I listen to other people's point of view before putting my own forward.
32. I tend to be open about how I am feeling.
33. In discussions I enjoy watching the maneuverings of other participants.
34. I prefer to respond to events in a spontaneous, flexible basis rather than plan things in advance .
35. I tend to be attracted to techniques such as network analysis, flow charts, branching programs, contingency planning etc.
36. It worries me if I have to rush out a piece of work to meet a tight deadline.
37. I tend to judge people's ideas on their practical merits.
38. Quiet, thoughtful people tend to make me feel uneasy.
39. I often get irritated by people who want to rush things.
40. It is more important to enjoy the present moment than to think about the past or future.
41. I think that decisions based on a thorough analysis of all the information are sounder than those based on intuition.
42. I tend to be a perfectionist.
43. In discussions, I usually produce lots of spontaneous ideas.
44. In meetings I put forward practical realistic ideas.
45. More often than not, rules are there to be broken.
46. I prefer to stand back from a situation and consider all the perspectives.
47. I can often see inconsistencies and weaknesses in other people's arguments.

48. On balance I talk more than I listen

49. I can often see better, more practical ways to get things done

50. I think written reports should be short and to the point.

51. I believe that rational, logical thinking should win the day.

52. I tend to discuss specific things with people rather than engaging in social discussion.

53. I like people who approach things realistically rather than theoretically.

54. In discussions I get impatient with irrelevancies and digressions.

55. If I have a report to write I tend to produce lots of drafts before settling on the final version.

56. I am keen to try things out to see if they work in practice .

57. I am keen to reach answers via a logical approach.

58. I enjoy being the one that talks a lot.

59. In discussions, I often find I am the realist, keeping people to the point and avoiding wild speculations.

60. I like to ponder many alternatives before making up my mind.

61. In discussions with people I often find I am the most dispassionate and objective.

62. In discussions I am more likely to adopt a 'low profile' than to take the lead and do most of the talking.

63. I like to be able to relate current actions to a longer term picture.

64. When things go wrong, I am happy to shrug it off and 'put it down to experience'.

65. I tend to reject wild, spontaneous ideas as being impractical.
66. It is best to think carefully before taking action.
67. On balance I do the listening rather than the talking .
68. I tend to be tough on people who find it difficult to adopt a logical approach .
69. Most times I believe the end justifies the means.
70. I don't mind hurting people's feelings so long as the job gets done.
71. I find the formality of having specific objectives and plans stifling.
72. I am usually one of the people who puts life into a party.
73. I do whatever is expedient to get the job done.
74. I quickly get bored with methodical, detailed work.
75. I am keen on exploring the basic assumptions,principles and theories underpinning things and events.
76. I am always interested to find out what people think.
77. I like meetings to be run on methodical lines, sticking to laid down agenda, etc.
78. I steer clear of subjective or ambiguous topics.
79. I enjoy the drama and excitement of a crisis situation.
80. People often find me insensitive to their feelings.

A.3 Sample of Background Evaluation Questionnaire

Purpose: This is a multiple choice/short answer type of exercise prepared to give the teaching staff a "snapshot" of the level of knowledge of the class at the start. No number grade will be assigned, but a note will be made of whether you did it or not.

Rules for Completion: This is a closed book exercise. No collaboration is allowed with others - this is a test of your knowledge. Try to do the exercise without interruption. When you are done, please note below roughly how long you actually spent on the exercise.

For the following, circle the letter of the correct answer or fill in the blank:

1. Which of the following would describe a constitutive relation for a material?

   (a) As pressure increases, temperature increases

   (b) As volume decreases, pressure increases

   (c) As the rate of stretching increases, tensile stress increases

2. In a conservative mechanical system, external forces can be represented as

   (a) the curl of a vector potential

   (b) the gradient of a scalar potential

   (c) the divergence of a vector potential

3. When we state for a system , it is implied that the frame of reference is

   (a) fixed in space

   (b) accelerating with respect to a fixed frame

   (c) either fixed or translating at a constant velocity with respect to a fixed frame

4. The Reynolds number represents the ratio of the following forces in a fluid flow:

   (a) inertia force to gravity force

   (b) pressure force to inertia force

   (c) inertia force to viscous force

   (d) inertia force to surface tension force

5. The symmetry of the fluid stress tensor results from all of the following except

   (a) conservation of linear momentum

   (b) conservation of angular momentum

   (c) the continuum hypothesis

   (d) conservation of energy

6. In a Newtonian fluid, the stress due to fluid motion is

   (a) independent of strain rate

   (b) a linear function of strain rate

   (c) a quadratic function of strain rate

7. If energy input to a viscous flow ceases, then any existing vorticity must

   (a) remain constant since angular momentum is conserved

   (b) eventually decay to zero

   (c) be converted into kinetic energy

Appendix B

Lectures

B.1 Lecture A - Theoretical

Introduction

Lifting surfaces in marine hydrodynamics typically have many applications such as hydrofoils, keels, rudders, propeller blades and yacht sails. A lifting surface is a thin streamlined body that moves in a fluid at a small angle of attack with a resultant lift force normal to the direction of flow.

Consider the foil in figure 1in a uniform free stream. The straight line joining the center of curvature of the leading edge to the trailing edge is the chord. The camber line is midway between the upper surface and the lower surfaces. The distance between the chord and the mean camber line is the camber. The angle a between the free stream and the chord line is called the angle of attack.

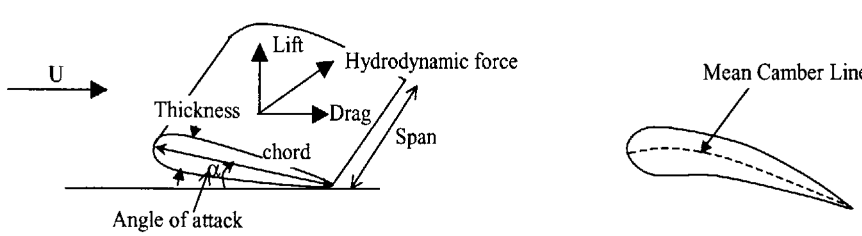


Figure B-1: Dimensions of a foil

The hydrodynamic force that points in the direction of the free stream is defined as the drag force, while the component normal to the free stream in the upward direction is the lift force. The lift and drag forces vary with the angle of attack. These forces are expressed non-dimensionally by defining the coefficients of lift and drag with respect to the planform area A.

$$A = span * chord \tag{B.1}$$

$$C_L = \frac{L}{\frac{1}{2}\rho U^2 A} \tag{B.2}$$

$$C_D = \frac{D}{\frac{1}{2}\rho U^2 A} \tag{B.3}$$

Models of Reality

All bodies in real life are best modelled as 3D objects. Assume a smooth body of arbitrary shape is placed in a steady, irrotational flow field with zero viscosity. DAlembert states that in 3D, there are no vector forces existing on the body; no lift and no drag. Solving Laplaces equation in 3D and the boundary value problem (BVP) gives a unique solution where the circulation is zero.

However, the case of zero vector forces everywhere is a little boring and it is often difficult to solve 3D problems and 2D modeling is often more appropriate. Flows around a foil are usually treated as two-dimensional problems where it is assumed that the span is infinite. For steady flow of an unbounded fluid without vorticity over a 2D body, Laplaces equation and the BVP do not have a unique solution because a circulation G can always be found as a solution. Then with a circulation G that will not violate Laplaces equation and the BVP in a uniform flow, DAlembert states that there is still zero horizontal force (zero drag) but G will produce lift.

$$\Gamma = \oint \vec{v} \cdot \vec{n} d\ell \tag{B.4}$$

Another way to understand that there is no drag force on the foil is to look at energy conservation in a potential flow. Recall that if drag existed on the foil, energy would be fed continuously into the fluid as the foil moved at a steady velocity and did work on the fluid against the drag force. But in the potential flow there is no viscosity and hence no way to dissipate the energy the foil would be adding to the fluid. Since we are assuming the problem is steady in a reference frame fixed with the foil, dE/dt = 0.

In other words, the energy E of the fluid is not changing with time. Therefore the foil cannot be continuously adding energy to the fluid, since there is no dissipation to balance the energy addition, and this in turn means that the foil is not working against any drag force.

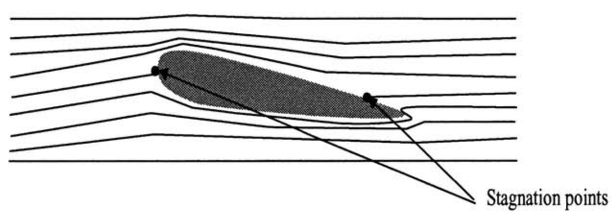


Figure B-2: Ideal flow about a foil

For the case of a foil at an angle of attack a in an ideal irrotational flow, potential theory prescribes that the velocity of the sharp trailing edge is infinite since this is an external corner flow. Stagnation points exist at the leading edge and on the upper surface of the foil near the trailing edge.

Circulation

If the stagnation point on the body is specified, this will result in a fixed circulation G, which will specify the amount of lift produced. Similarly, if G is specified, this will fix the stagnation points and produce a specific lift force. The body is still in a steady, irrotational, inviscid flow; drag remains zero in either case.

Since lift is required, how can we specify the stagnation point at a fixed point on the body? The first step is to choose the ideal body configuration. For a body that is not foil-shaped, or streamlined, flow separation can occur from the surface of the body, reducing the circulation and associated lift. It was observed that a foil-shaped object helps guide the flow around the body so that it does not separate until it leaves the trailing edge.

Real fluid particles cannot move at infinity relative to each other due to viscous effects (particles exert shear forces on each other) and therefore the flow around the trailing edge will have a finite velocity. Since real flows tend to separate when rounding a corner, like the trailing edge of a foil, the ideal body shape is a foil positioned so that it causes the flow to leave the trailing edge at a finite velocity in a smooth tangential manner. This is known as the Kutta condition and is satisfied at small angles of attack.

From experiments, it was observed that at an angle of attack of 0 to 10 degrees, the flow detaches at roughly the trailing edge on the foil, resulting in a maximum lift range.

How much Lift?

So, how much lift will be generated using potential flow theory if the stagnation point is at the trailing edge of the foil? Now the 2D boundary value problem is specified as:

$$\text{Perturbation potential:} \quad \phi \tag{B.5}$$

$$\text{Total Potential:} \quad \Phi = -Ux + \phi \tag{B.6}$$

$$\text{Governing Equation:} \quad \nabla^2 \phi = 0 \tag{B.7}$$

$$\text{K.B.C. on the foil:} \quad \frac{\partial \phi}{\partial n} = 0 = U\frac{\partial x}{\partial n} + \frac{\partial \phi}{\partial n} = Un_x \tag{B.8}$$

$$\text{At infinity:} \quad \nabla\phi \rightarrow 0 \text{as } r \rightarrow \infty \tag{B.9}$$

$$\text{Kutta condition:} \quad \nabla\phi < \infty \text{ at T.E.} \tag{B.10}$$

This BVP now has a unique solution and thus a unique lifting force for the given stagnation point at the trailing edge (T.E.).

From the solution of f of this BVP, we can then obtain the resulting G and associated lift force from the Kutta-Joukowsky theorem.

Kutta-Joukowsky theorem (2D)

$$\text{Kutta-Joukowsky Theorem:} \quad L = -\rho U \Gamma \tag{B.11}$$

A simple proof of the Kutta-Joukowsky theorem for a thin foil (thickness ¡¡ chord) can be obtained as follows:

Let a be small enough so that every point on the foil surface is almost parallel to the direction of flow. The upward force per spanwise unit length on the element dx is:

$$(p_L - p_U)dx$$

where p_L and p_U are the pressures on the lower and upper surfaces of the foil.

Bernoullis equation gives:

$$(p_L - p_U) = \frac{1}{2}(U_U^2 - U_L^2) = \frac{1}{2}(U_U - U_L)(U_U + U_L)$$

For a thin foil, the variations of the velocity from the free-stream velocity U will be small and we may approximate this by:

$$(p_L - p_U) = \rho U(U_U - U_L)$$

Hence the total lift per unit span is:

$$L = \rho U \int_{-\frac{\ell}{2}}^{\frac{\ell}{2}} (U_U - U_L) dx$$

The circulation physically around a contour and just outside the boundary layer may be approximated by:

$$\Gamma = \int_{-\frac{\ell}{2}}^{\frac{\ell}{2}} U_L dx + \int_{-\frac{\ell}{2}}^{\frac{\ell}{2}} U_U dx = -\int_{-\frac{\ell}{2}}^{\frac{\ell}{2}} (U_U - U_L) dx$$

Thus by comparison $L = -\rho U \Gamma$, which gives the Kutta-Joukowsky theorem.

From the above demonstration, we see that for a lifting force to exist on a foil, the pressure on the upper surface of the foil must be diminished and the velocity increased relative to the pressure and the velocity on the lower surface of the foil, producing a net upward force. These pressure and velocity changes are a result of circulation.

B.2 Lecture B - Intuitive

Introduction What are the characteristics of a lifting surface?

Lifting surfaces in marine hydrodynamics typically have many applications such as hydrofoils, keels, rudders, propeller blades and yacht sails. A lifting surface is a thin streamlined body that moves in a fluid at a small angle of attack with a resultant lift force normal to the direction of flow.

Consider the foil in figure 1in a uniform free stream. The straight line joining the center of curvature of the leading edge to the trailing edge is the chord. The camber line is midway between the upper surface and the lower surfaces. The distance between the chord and the mean camber line is the camber. The angle between the free stream and the chord line is called the angle of attack.

The hydrodynamic force that points in the direction of the free stream is defined as the drag force, while the component normal to the free stream in the upward

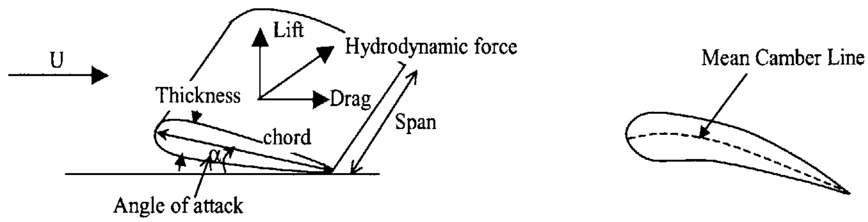


Figure B-3: Dimensions of a foil

direction is the lift force. The lift and drag forces vary with the angle of attack. These forces are esxpressed nondimensionally by defining the coefficients of lift and drag with respect to the planform area A.

$$A = span * chord$$

$$C_L = \frac{L}{\frac{1}{2}\rho U^2 A}$$

$$C_D = \frac{D}{\frac{1}{2}\rho U^2 A}$$

Flow Pattern Near a Wing

Consider a stationary wing in the middle of a wind tunnel; air flows past it from left to right. Assume that viscosity is small but not zero, the airflow is not significantly turbulent and no fluid can flow through the surface of the wing.

Upstream of the wing (near the left edge of the figure) is a number of smoke injectors. Seven of them are on all the time, injecting thin streams of purple smoke. The smoke is carried past the wing by the air flow, making visible streamlines.

In addition, on a five-times closer vertical spacing, pulsed streamers are injected. The smoke is turned on for 10 milliseconds out of every 20. In the figure, the blue smoke was injected starting 70 milliseconds ago, the green smoke was injected starting 50 milliseconds ago, and so on.

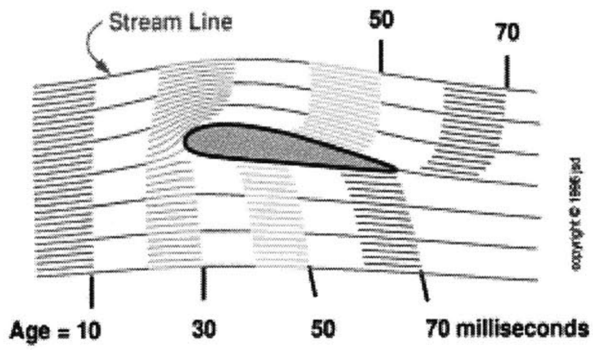


Figure B-4: Flow Past a Wing

Notice that the air just ahead of the wing is moving not just left to right but also upward. Similarly, the air just aft of the wing is moving not just left to right but also downward Downwash behind the wing is relatively easy to understand; the whole purpose of the wing is to impart some downward motion to the air (Why? To create lift on the wing as a reaction force). The upwash in front of the wing is a bit more interesting. Air is a fluid, which means it can exert pressure on itself as well as other things. The air pressure strongly affects the air, even the air well in front of the wing.

Along the leading edge of the wing there is a stagnation point. On an airplane, the stagnation line runs the length of the wingspan, but since figure B-4 shows only a cross section of the wing, all we see of the stagnation line is a single point. Another stagnation point exists on the trailing edge. It marks the place where air that passed above the wing rejoins air that passed below the wing. It is called stagnation point because the air velocity at that point is zero; the air is stagnant there.

Figure B-5 introduces some additional useful concepts. Since the air near the wing is flowing at all sorts of different speeds and directions, the question arises of what is the "true" airspeed in the wind tunnel. The logical thing to do is to measure the velocity of the free stream before it has been disturbed by the wing.

The pulsed streamers give us a lot of information. Regions where the pulsed streamers have been stretched out are high velocity regions. Conversely, regions where the pulsed streamers cover a small distance in 10 milliseconds must be low-velocity regions. The minimum velocity is zero. That occurs near the front and rear

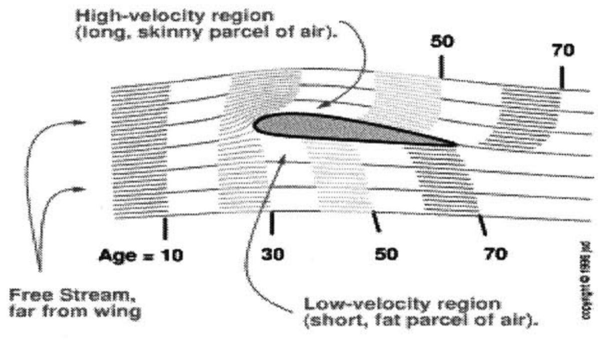


Figure B-5: Velocity Field of a Wing

stagnation points.

Another thing that should be noticed is that in low velocity regions, the streamlines are farther apart from each other (conservation of mass). At reasonable airspeeds, the wing doesn't push or pull on the air hard enough to change its density. The long, thin parcels of air flowing past a particular point show a region of high velocity and the short wider parcels flowing by show regions of low velocity.

The most remarkable thing about this figure is that the blue smoke that passed slightly above the wing got to the trailing edge 10 or 15 milliseconds earlier than the corresponding smoke that passed slightly below the wing. If this were not true, it would be impossible for the wing to produce lift. This is because a difference in the fluid velocity on the upper and lower wing surface means a difference of pressure also; this pressure difference produces lift.

A delay of particles is not forbidden. Consider the scenario depicted in figure B-6.

A river of water is flowing left to right. Using a piece of garden hose, siphon some water out of the river, let it waste some time going through several feet of coiled-up hose, and then return it to the river. The water that went through the hose will be delayed. The delayed parcel of water will never catch up with its former neighbors; it will not even try to catch up. Note that delaying the water did not require compressing the water, nor did it require friction(assuming the hose was frictionless on the inside).

The same story applies to air. Air flowing past an obstacle will be delayed. In fact, air that comes arbitrarily close to a stagnation line(or point if looking at a

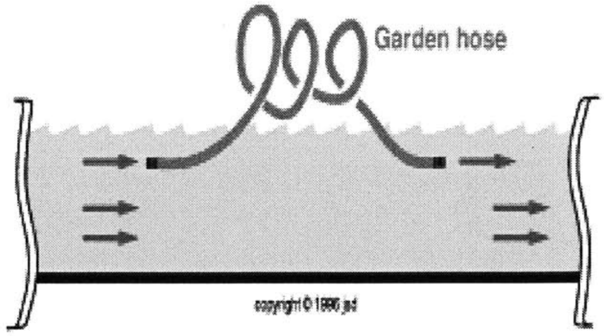


Figure B-6: Delay is Not Forbidden

cross-section) will be delayed an arbitrarily long time. The air molecules just hang around in the vicinity of the stagnation line. This delay occurs even when the wing is producing zero lift, as shown in the top panel of figure 5. You can see that in all cases the air that hit the stagnation line dead-on the middle blue streamer never makes it to the trailing edge in any of these figures. So velocity magnitude can change along a streamline.

When a wing is not producing lift it is just a slight obstacle to the airflow. Air passing near the wing is slightly delayed, but that's about all. Air that passed slightly above the wing is delayed about the same amount as the corresponding air that passed below the wing. When the wing is producing lift, the airflow patterns become much more interesting.

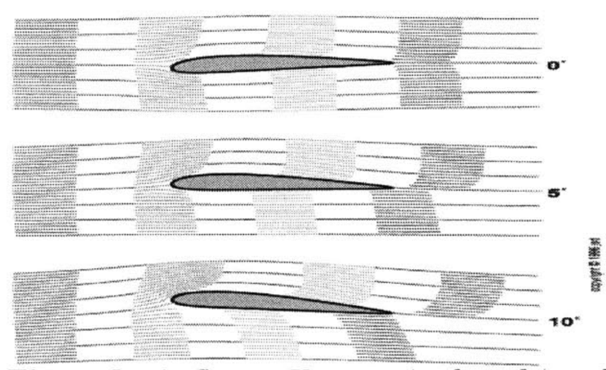


Figure B-7: Airflow at Various Angles of Attack

Air that passes above the wing reaches the trailing edge substantially earlier than it would have if the wing had not been producing lift. Air that passes below the wing is substantially delayed. These effects extend for quite a distance above and below the wing.

A wing (when it is producing lift) is amazingly effective at speeding up the air above it. Even though the air that passes above the wing has a longer path, it gets to the back earlier than the corresponding air that passes below the wing.

The change in speed is only temporary. As the air reaches the trailing edge and thereafter, it quickly returns to its original, free-stream velocity.

Pressure Patterns Near a Wing

Figure B-8 is a contour plot that shows what the pressure is doing in the vicinity of the wing. All pressures will be measured relative to the ambient atmospheric pressure in the free stream. The blue-shaded regions indicate suction, i.e. negative pressure relative to ambient, while the red-shaded regions indicate positive pressure relative to ambient. The dividing line between pressure and suction is also indicated in the figure.

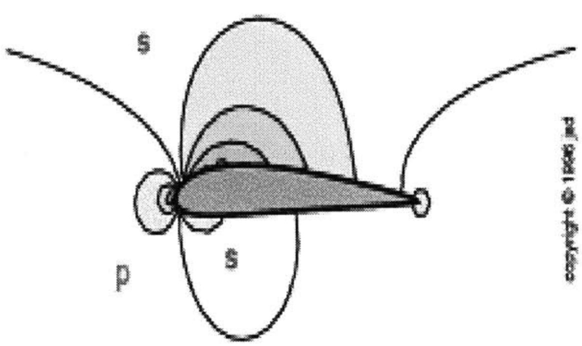


Figure B-8: Pressure Near a Wing

The maximum positive pressure on the foil occurs right at the stagnation points. The maximum suction depends on the angle of attack and on the detailed shape of the airfoil. It is clear that the front quarter or so of the wing does half of the lifting. Another thing to notice is that suction acting on the top of the wing is vastly more important than pressure acting on the bottom of the wing. In figure 6 the wing is flying at an angle of attack of 3 degrees, a reasonable "cruise" value.

At this angle of attack, there is almost no high pressure on the bottom of the wing; indeed there is mostly suction there. The only reason the wing can support the weight of the airplane is that there is more suction on the top of the wing.

At higher angles of attack, above-atmospheric pressure does develop below the wing, but it is always less pronounced than the below-atmospheric pressure above the wing.

Stream Line Curvature

Figure B-9 shows what happens near the wing when we change the angle of attack. You can see that as the velocity changes, the pressure changes also.

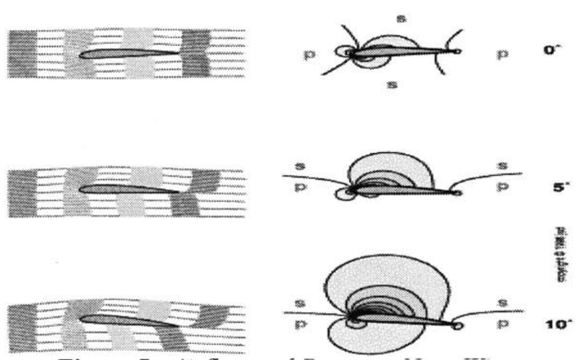


Figure B-9: Airflow and Pressure Near Wings

It turns out that given the velocity field, it is rather straightforward to calculate the pressure field. From Bernoullis equation, it is clear that as the velocity increases, the pressure decreases.

Cambered Foils

The maximum difference between the mean camber line and the chord line is the amount of camber. A symmetric foil has zero camber. The airflow and pressure patterns for such an airfoil are shown in figure B-11.

At small angles of attack, a symmetric airfoil works better than a highly cambered airfoil. Conversely, at high angles of attack, a cambered airfoil works better than the

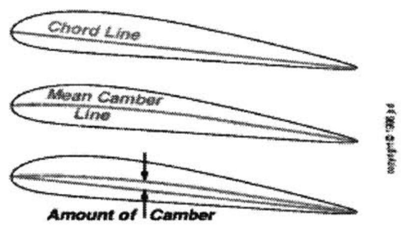


Figure B-10: Airfoil Terminology

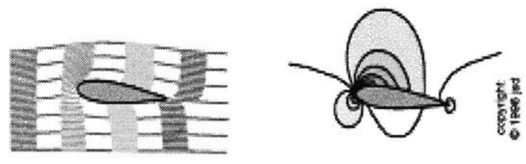


Figure B-11: Symmetric Airfoil

corresponding symmetric airfoil. If the angle of attack is too large, stall occurs; i.e. the lift coefficient rapidly decreases. The existence of a smooth leading edge allows for a slightly larger angle of attack before stall and separation of the flow occur. An example of this is shown in figure B-12. The airfoil designated "631-012" is symmetric, while the airfoil designated "631-412" airfoil is cambered; otherwise the two are identical. At any normal angle of attack (up to about 12 degrees), the two airfoils produce virtually identical amounts of lift. Beyond that point the cambered airfoil has a big advantage because it does not stall until a much higher relative angle of attack. As a consequence, its maximum coefficient of lift is much greater.

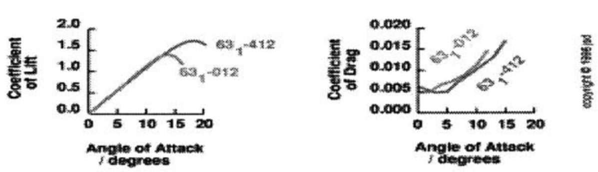


Figure B-12: Camber Fends Off The Stall

At high angles of attack, the leading edge of a cambered wing will slice into the wind at less of an angle compared to the corresponding symmetric wing. This doesn't prove anything, but it provides an intuitive feeling for why the cambered wing has more resistance to stalling.

The amount of camber on a typical modern airfoil is only 1 or 2 percent obviously not crucial. One reason wings are not more cambered is that any increase would require the bottom surface to be concave which would be a pain to manufacture. Another reason is that large camber is only really beneficial near the stall and it suffices to create lots of camber by extending flaps when needed. Reverse camber is clearly a bad idea (since it causes earlier stall) so aircraft that are expected to perform well upside-down have symmetric airfoils.

We have seen that under ordinary conditions, the amount of lift produced by a wing depends on the angle of attack, but hardly depends at all on the amount of camber. This makes sense. In fact, an airplane would be 'unflyable' if the coefficient of lift were determined solely by the shape of the wing. Since the amount of camber doesn't often change in flight, there would be no way to change the coefficient of lift. In reality, the pilot (and the trim system) continually regulate the amount of lift by regulating the all-important angle of attack.

Thin-wing Theory

The wing used on the Wright brothers' first airplane is thin, highly cambered, and quite concave on the bottom. This is shown in figure B-13. There is no significant difference between the top surface and the bottom surface same length, same curvature. Still, the wing produces lift, using the same lift-producing principle as any other airfoil Similar remarks apply to the sail of a sailboat. It is a very thin wing, oriented more-or-less vertically, producing sideways lift.

Even a thin flat object such as a barn door will produce lift, if the wind strikes it at an appropriate angle of attack. The airflow pattern (somewhat idealized) for a barn door (or the wing on a dime-store balsa glider) is shown in figure B-14. Once again, the lift-producing mechanism is the same.

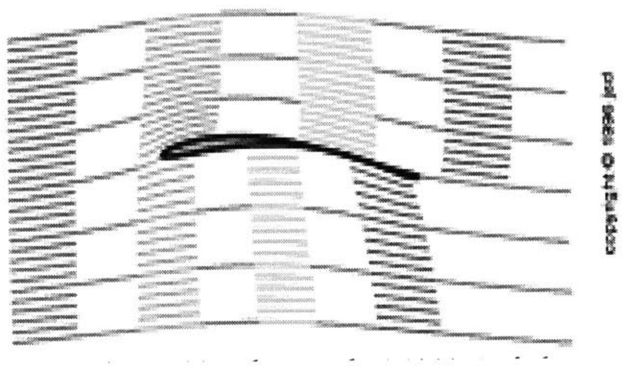


Figure B-13: The Wrights' 1903 Airfoil

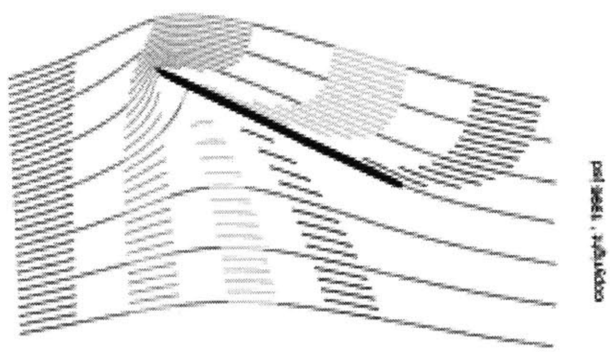


Figure B-14: Barn Door Natural Airflow

Circulation

You may be wondering whether the flow patterns shown in figure 12 or the earlier figures are the only ones allowed by the laws of hydrodynamics. The answer is: almost, but not quite. Figure 13 shows the barn door operating with the same angle of attack (and the same airspeed) as in figure B-14, but the airflow pattern is different.

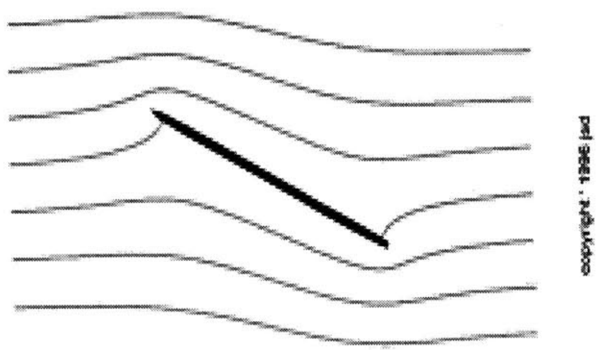


Figure B-15: Barn Door Unnatural Stream Line

The new airflow pattern is highly symmetric. The front stagnation line is a certain distance behind the leading edge; the rear stagnation line is the same distance ahead of the trailing edge. This airflow pattern produces no lift. The difference between figure B-14 and figure B-15 is circulation figure B-14 has circulation while figure B-15 does not.

To understand circulation and its effects, first imagine an airplane with barn-door wings, parked on the ramp on a day with no wind. Then imagine stirring the air with a paddle, setting up a circulatory flow pattern, flowing nose-to-tail over the top of the wing and tail-to-nose under the bottom (clockwise in this figure). This is the flow pattern for pure circulation, as shown in figure B-16.

Then imagine that a headwind springs up (left to right in the figure). At each point in space, the velocity fields will add. The circulatory flow and the wind will add above the wing, producing high velocity and low pressure there. The circulatory flow will partially cancel the wind below the wing, producing low velocity and high pressure there.

If we take the noncirculatory left-to-right flow in figure B-15 and add various

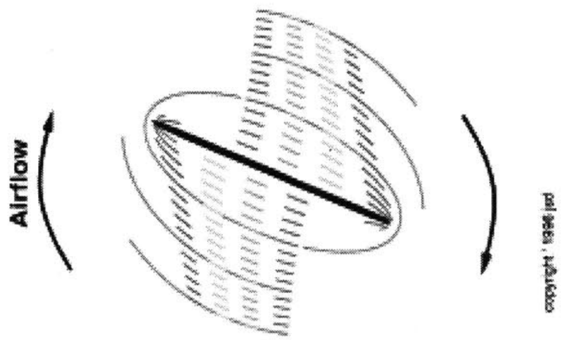


Figure B-16: Barn Door Pure Circulation

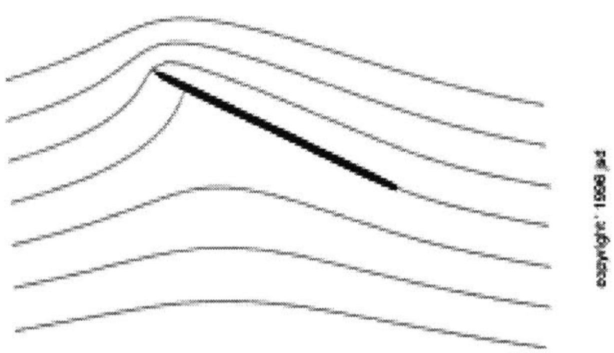


Figure B-17: Barn Door Natural Stream Lines amounts of circulation, we can generate all the flow patterns consistent with the laws of hydrodynamics including the actual natural airflow shown in figure B-14 and figure B-17.

There is nothing special about barn doors; real foils have analogous airflow patterns, as shown in figure B-18, figure B-19, and figure B-20 .

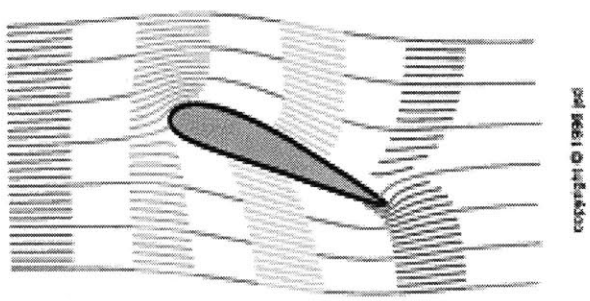


Figure B-18: Unnatural Airflow Angle of Attack but No Circulation

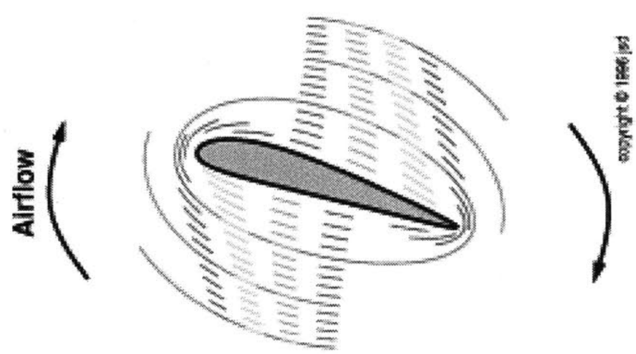


Figure B-19: Pure Circulation

How Much Circulation? The Kutta Condition

In real flight situations, precisely enough circulation will be established so that the rear stagnation point is right at the trailing edge, so no air needs to turn the corner there. Of course, the circulation that cancels the flow around the trailing edge more or less doubles the flow around the leading edge.

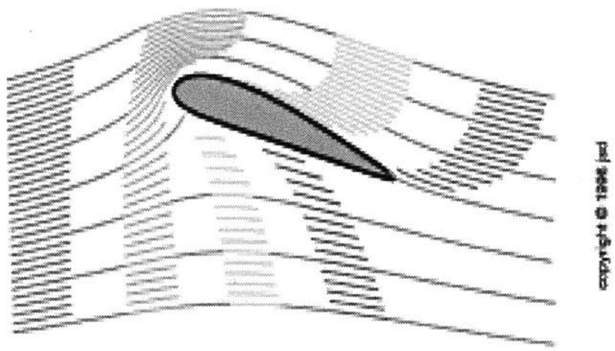


Figure B-20: Normal, Natural Airflow

The general rule - called the Kutta condition - is that the fluid must have a finite velocity at the sharp trailing edge. In potential flow theory, the velocity at the trailing edge is infinite. In reality, viscosity at the boundary layer and the starting vortex at the sharp edge play an important role in maintaining a finite velocity at that trailing edge. As the angle of attack increases, the amount of circulation needed to meet the Kutta condition increases. Here is a direct way of demonstrating the Kutta condition: At a safe altitude, start with the airplane in the clean configuration in level flight, a couple of knots above the speed where the stall warning horn comes on. Maintaining constant pitch attitude and maintaining level flight, extend the flaps. The stall warning horn will come on. There is no need to stall the airplane; the warning horn itself makes the point.

This demonstration makes it clear that the flap (which is at the back of the wing) is having a big effect on the airflow around the entire wing, including the stall-warning detector (which is near the front). Extending the flaps (while maintaining constant pitch and constant direction of flight) increases the angle of attack. This increases the circulation, which trips the stall-warning detector.

How Much Lift? The Kutta-Joukowsky Theorem

The Kutta-Joukowsky theorem states that lift force is equal to the airspeed times the circulation times the density for a 2D wing.

$$L = -\rho U \Gamma$$

Since circulation is proportional to the coefficient of lift and to the airspeed, this new notion is consistent with our previous knowledge that the lift should be proportional to the coefficient of lift times airspeed squared.

You can look at a velocity field and visualize the circulation. In figure B-21, the vertical black line shows where the 70 millisecond timeline would have been if the wing had been completely absent. The actual 70 millisecond timeline is given by the right-hand edge of the blue streamers.

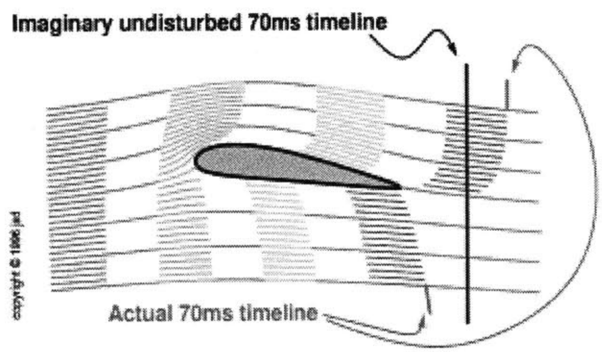


Figure B-21: Circulation Advances Upper and Retards Lower Streamers

Because of the circulatory contribution to the velocity, the streamers above the wing are at a relatively advanced position, while the streamers below the wing are at a relatively retarded position. If you refer back to figure B-9, you can see that circulation is proportional to angle of attack. In particular, note that when the airfoil is not producing lift there is no circulation the upper streamers are not advanced relative to the lower streamers.

The same thing can be seen by comparing figure B-18 to figure B-20 when there is no circulation the upper streamers are not advanced relative to the lower streamers.

Lift Requires Circulation and Vortices

The circulation necessary to produce lift can be attributed to a bound vortex line. It binds to the wing and travels with the airplane. The question arises, what happens to this vortex line at the wingtips?

The answer is that the vortex spills off each wingtip. Each wing forms a trailing vortex (also called wake vortex) that extends for miles behind the airplane. These trailing vortices constitute the continuation of the bound vortex. See figure B-22. Far behind the airplane, possibly all the way back at the place where the plane left ground effect, the two trailing vortices join up to form an unbroken vortex line.

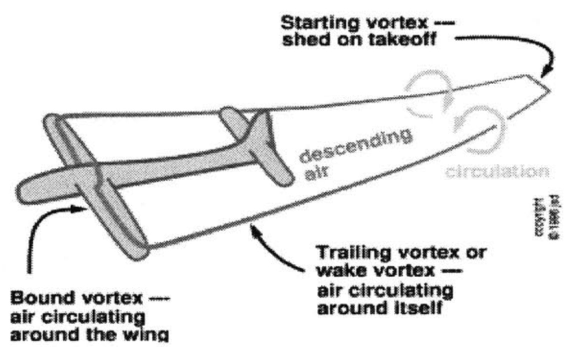


Figure B-22: Bound Vortex, Trailing Vortices

The air rotates around the vortex line in the direction indicated in the figure. We know that the airplane, in order to support its weight, has to yank down on the air. The air that has been visited by the airplane will have a descending motion relative to the rest of the air. The trailing vortices mark the boundary of this region of descending air.

It doesn't matter whether you consider the vorticity to be the cause or the effect of the descending air - you can't have one without the other.

Lift must equal weight times load factor, and we can't easily change the weight, or the air density, or the wingspan. Therefore, when the airplane flies at a low airspeed, it must generate lots of circulation.

B.3 Lecture C - Experimental

Introduction

Lifting surfaces in marine hydrodynamics typically have many applications such as hydrofoils, keels, rudders, propeller blades and yacht sails. A lifting surface is a thin streamlined body that moves in a fluid at a small angle of attack with a resultant lift force normal to the direction of flow.

Consider the foil in figure 1in a uniform free stream. The straight line joining the center of curvature of the leading edge to the trailing edge is the chord. The camber line is midway between the upper surface and the lower surfaces. The distance between the chord and the mean camber line is the camber. The angle between the free stream and the chord line is called the angle of attack.

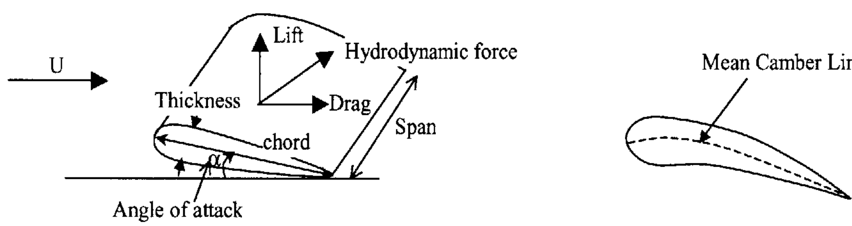


Figure B-23: Dimensions of a foil

The hydrodynamic force that points in the direction of the free stream is defined as the drag force, while the component normal to the free stream in the upward direction is the lift force. The lift and drag forces vary with the angle of attack. These forces are expressed non-dimensionally by defining the coefficients of lift and drag with respect to the planform area A.

$$A = span * chord \tag{B.12}$$

$$C_L = \frac{L}{\frac{1}{2}\rho U^2 A} \tag{B.13}$$

$$C_D = \frac{D}{\frac{1}{2}\rho U^2 A} \tag{B.14}$$

Mechanism of Lift Generation

It is possible to apply potential flow theory with no circulation to an airfoil, leading to the flow pattern shown in figure B-24. It is apparent from the figure that the flow pattern has some peculiar features.

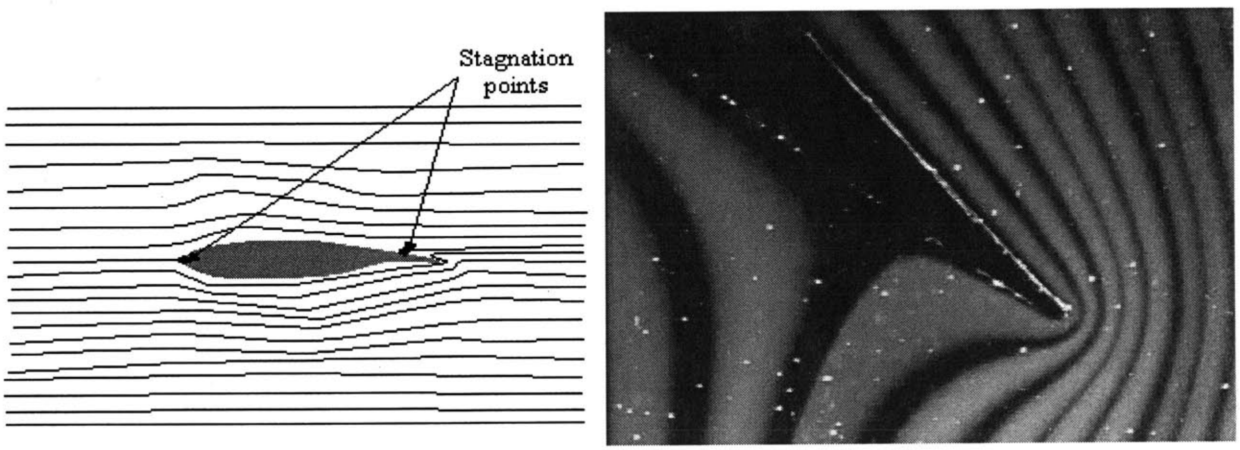


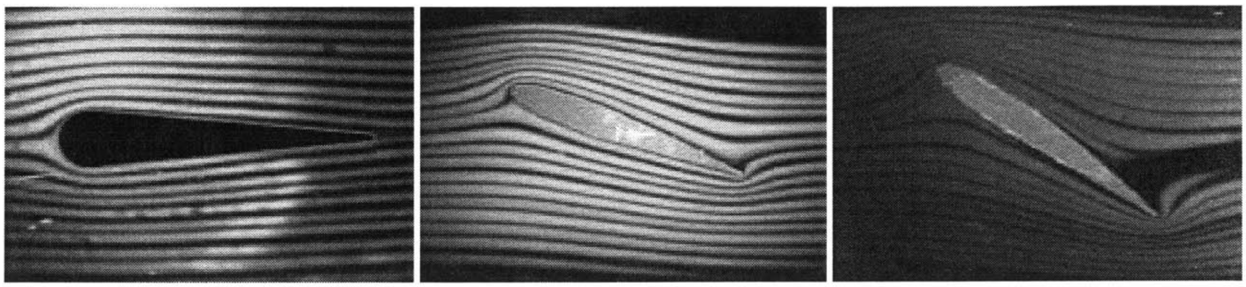
Figure B-24: a - Potential Flow around an airfoil b - Potential flow at trailing edge

There exists a stagnation point on the upper surface of the foil just forward of the trailing edge and the flow travels from the lower side to the upper side around the trailing edge. Consider the pressure distribution associated with this flow. Consider the pressure distribution associated with this flow. Recall that for both potential and viscous flow, and deducing from the centrifugal forces acting on a particle moving in a curved path, the pressure gradient normal to a streamline of radius r is given by

$$\frac{\partial p}{\partial n} = \frac{\rho \nu^2}{r} \tag{B.15}$$

This indicates that large pressure gradients are associated with small radii of curvature (recall flow around a corner). The Bernoulli equation shows that such rapid changes of pressure are accompanied by corresponding rapid changes in velocity and that the velocity increases with diminishing radius (and pressure) and theoretically reaches an infinite value at a corner(radius = 0). Therefore, we can conclude that the flow pattern shown in figure B-24 indicates infinite velocities at the trailing edge.

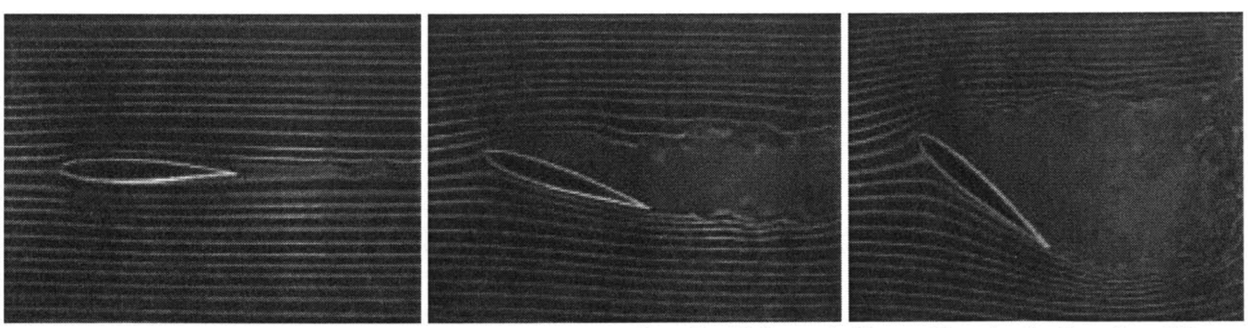
Figure B-25 below shows a foil at two different angles of attack in a potential flow field.



Potential Flow (angle of attack = 0 degrees) | Potential Flow (angle of attack = 22 degrees) | Potential Flow (angle of attack = 45 degrees)

Figure B-25: Potential Flow around a foil

Now consider the foil in a viscous flow (B-26) at the same angles of attack. Note the differences between the potential flow and the viscous flow. Due to pressure drag and friction drag, a boundary layer develops and the potential flow pattern is no longer valid.



Viscous Flow (angle of attack = 0 degrees) | Viscous Flow (angle of attack = 22 degrees) | Viscous Flow (angle of attack = 45 degrees)

Figure B-26: Experimental flow around a foil

As the boundary layer develops and friction forces build up, the flow pattern changes. The stagnation point moves to the trailing edge and circulation is created. The circulation G is defined as

$$\Gamma = \oint \vec{v} \cdot \hat{n} d\ell \tag{B.16}$$

The velocity on the top surface is lower than that on the lower surface. A pressure distribution is developed around the foil. The pressure changes and the velocity changes are a result of a non-zero circulation around the foil. Notice that even in a viscous flow, a symmetrical foil at a zero angle of attack will not produce lift. Circulation (and therefore lift) is generated when an asymmetry is introduced, either by introducing a camber or an angle of attack.

The result at the trailing edge is two streams travelling at different velocities. This causes a starting vortex at the trailing edge. One particularly interesting feature is that a reduced pressure exists near the trailing edge that acts to deflect the flow from the underside to the upper surface of the foil. The vortex is eventually shed and extends to infinity, leaving a positive pressure at the lower surface and a negative pressure at the upper surface.

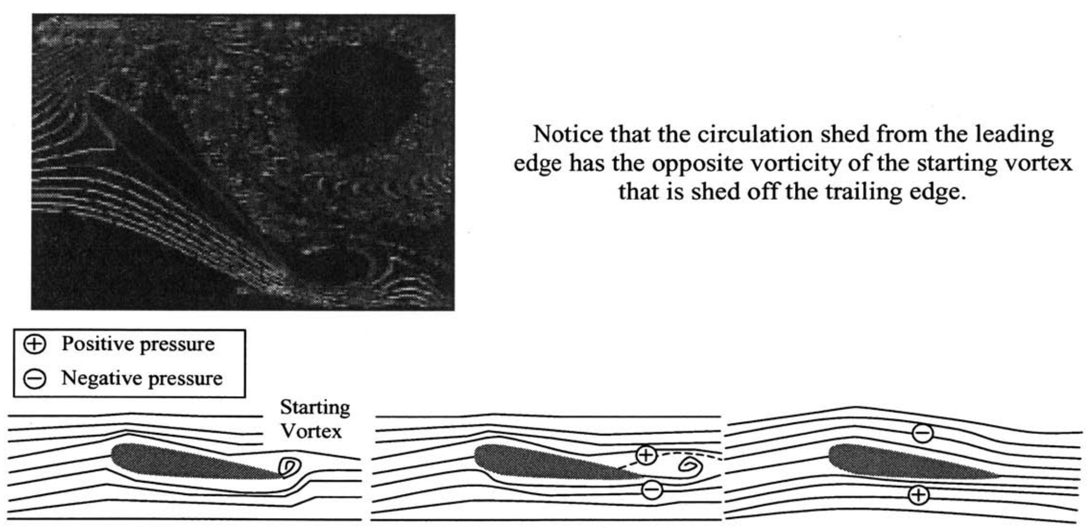


Figure B-27: Development of starting vortex

Once the flow pattern has been established, the effect of these friction forces are confined to the boundary layers on the surface of the foil and to the thin vortex sheet in the wake of the foil and at the trailing edge. In the remainder of the flow, velocity gradients are small and the flow is smoothly curved, therefore it may be expected that potential flow theory would be a satisfactory tool for analyzing the airfoil performance.

There is one situation in which an infinite ideal fluid moving at a uniform velocity can exert a force perpendicular to its general direction of motion on a body immersed in it. This arises when circulation G exists about the foil.

By the principle of conservation of angular momentum, the formation of the vortex must have resulted in the development of a rotary motion of equal angular momentum, but in the opposite direction(as can be seen in figure B-28).

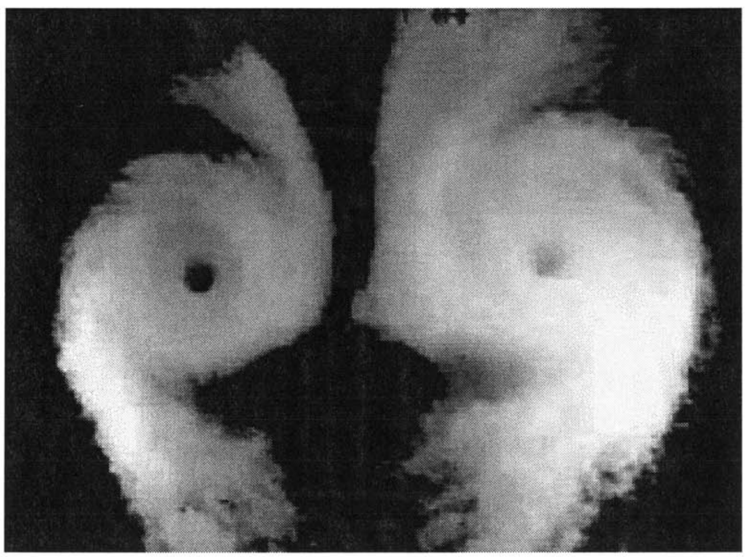


Figure B-28: Wing-tip vortices

This circulation in fact, does exist and surrounds the airfoil roughly as sketched in figure B-29.

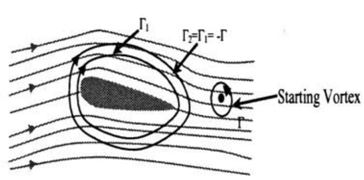


Figure B-29: Circulation around an airfoil

The Experiment

Consider a symmetrical airfoil (NACA 0012) in a wind tunnel(see B-30). Several locations on the surface of the foil have static pressure tappings connected to a multi-tube manometer.

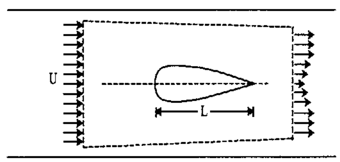


Figure B-30: Foil in a wind tunnel

Since the foil is symmetric, pressure readings are only taken on a single side of the foil. The pressure profile can be observed on both sides of the foil by making use of positive and negative angles of incidence.

The initial test shows that a negative pressure, a suction pressure, exists on the upper surface, and a smaller positive pressure exists on the lower surface (See figure B-31). The suction pressure in fact contributes about three quarters of the lift force.

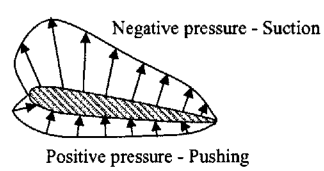


Figure B-31: Pressure distribution about an airfoil

According to Bernoulli, the corresponding static pressure on the upper surface is diminished and the pressure on the lower surface is increased. At the same time, the proportion of the fluid stream flowing above the airfoil increases, the flow below the airfoil decreases and the position of the forward stagnation point is displaced downwards (figure B-32). The velocity at the trailing edge is no longer infinite. The condition of finite velocity at the trailing edge is known as the Kutta condition.

The next test (figure B-33) shows that when the angle of attack exceeds about 11^o, there is a sudden fall in the suction pressure which, instead of coming to a sharp

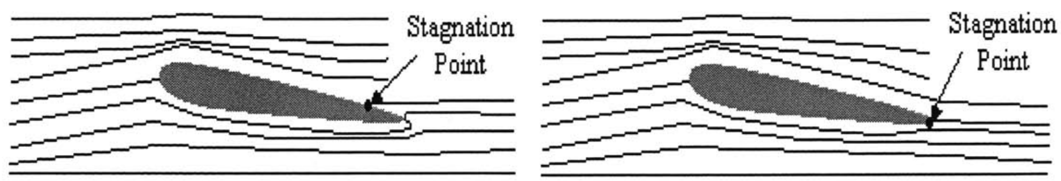


Figure B-32: a Potential Flow stagnation point b Viscous Flow stagnation point

peak near the leading edge, becomes nearly uniform across the whole chord of the airfoil. The airfoil is then stalled.

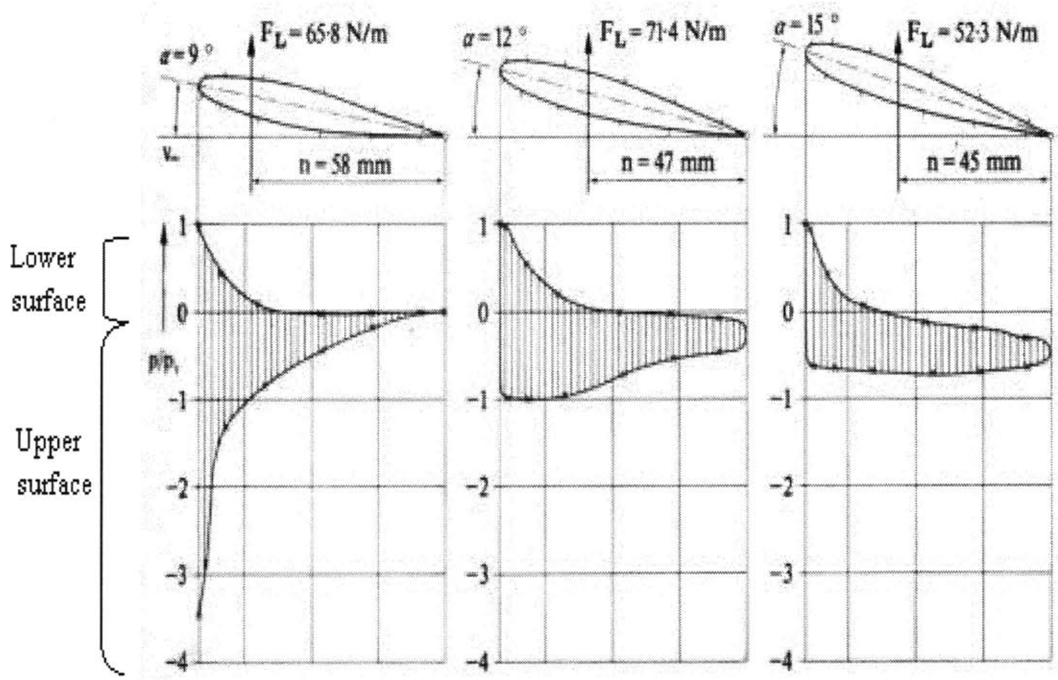


Figure B-33: Pressure Distributions at varying angles of attack

Observe the foil in the smoke tunnel (figure B-34) at high angles of attack and note that the flow separates near the leading edge and gives rise to a wide turbulent wake.

Kutta-Joukowsky Theorem

Now that we have observed that circulation creates lift, how much lift is created? The Kutta-Joukowsky theorem for 2D foils states that the lift force is equal to the

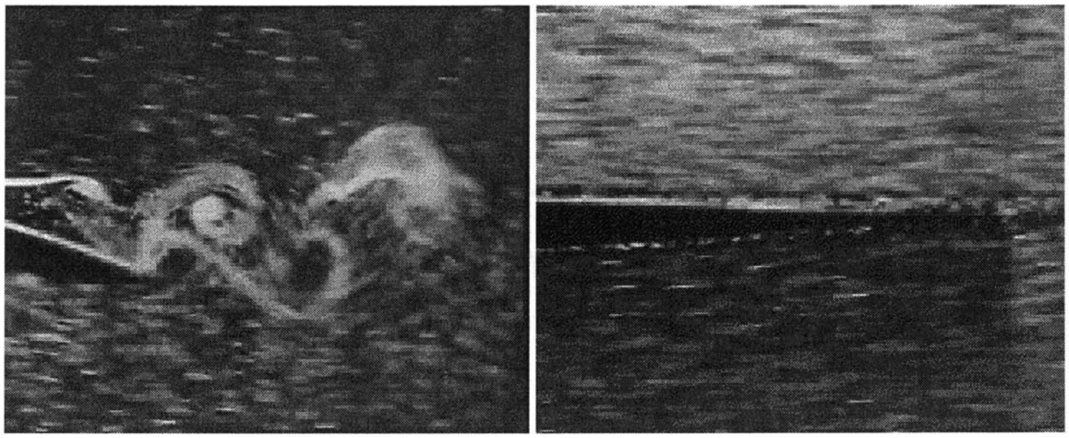


Figure B-34: a - Foil in viscous flow at varying angles of attack b - Foil of varying thickness in viscous flow

circulation times the density times the velocity of the fluid. The minus sign is by convention due to the direction of circulation.

The validity of the Kutta-Joukowsky theorem can be confirmed as follows. Figure 10 shows the velocity distribution around the airfoil at an angle of attack of 6^o, calculated from the observed pressure using the Bernoulli equation. To allow for the presence of the boundary layer, these calculated velocities are assumed to apply to a profile lying at an arbitrary distance of 1mm from the airfoil surface and the curves show velocity against the length of this profile, measured from the leading edge. The corresponding circulation is calculated from the circulation equation and from the corresponding lift coefficient. The resulting value $C_L = 0.6$, is in reasonable agreement with the value $C_L = 0.567$ calculated from the pressure distribution shown in figure 8.

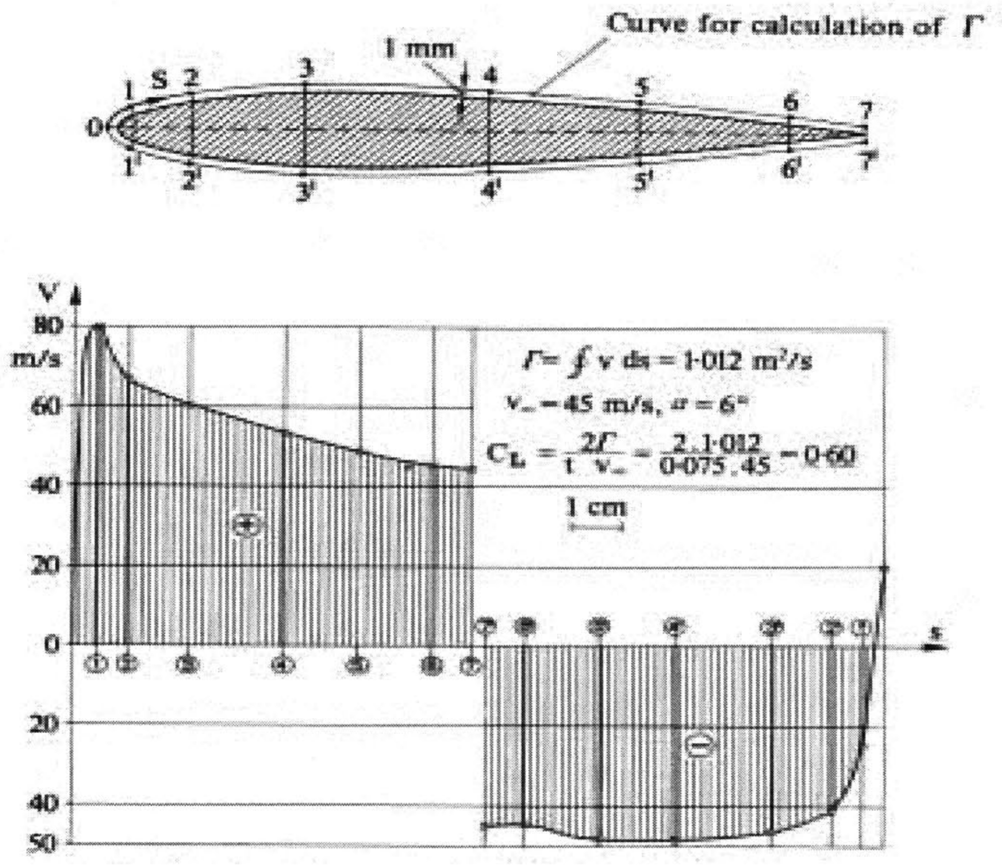


Figure B-35: Circulation around airfoil Kutta-Joukowsky theorem

Appendix C

Atomized Indexed Element

C.1 Indexed, Atomized Circulation Subset

A

The circulation is a scalar integral of the velocity field that can be related to its vorticity. Denoted by the symbol Γ, circulation is defined by the line integral:

$$\Gamma \equiv \int_C V \cdot dc$$

where **V** is the velocity and ***dc*** the line element along a closed curve **C.**

Theorist	7
Reflector	4
Background	5

Pointing to: B [Circulation]

B

By utilizing Stokes' Theorem, the circulation may be expressed also as a surface integral:

$$\Gamma \equiv \int_C V \cdot dc = \iint_S n \cdot (\nabla \times V) dS = \iint_S \omega \cdot n dS$$

where the surface integral **S** is any surface whose edge is the curve **C** and whose normal is n.

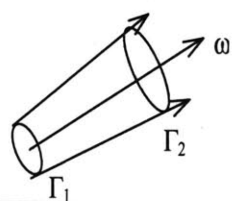
Theorist	9
Reflector	3
Background	6

Pointing to:

- B [Circulation]
- C [Circulation]
- E [Circulation]
- F [Circulation]
- D [Background]

C			
We may call Γ the vorticity flux through the area **S** enclosed by the curve **C**, in analogy with the magnetic flux enclosed by a wire loop carrying an electric current.			
Theorist	6	Pointing to:	D [Circulation]
Reflector	8		E [Circulation]
Background	4		

D



This vortex tube shows the vortex lines and two curves on the tube lateral surface qt which the circulation is Γ_1 and Γ_2.

Theorist	3	Pointing to:	F [Circulation]
Reflector	9		E [Circulation]
Background	3		

E

The circulation Γ_1 enclosed by the curve $\mathbf{C_1}$ may be evaluated in terms of an area integral extending over the lateral surface $\mathbf{S_{lat}}$ and the area $\mathbf{S_2}$:

$$\Gamma \equiv \int_{C_1} V \cdot dc_1 = \iint_S \omega \cdot n \; dS_{lat} = \iint_S \omega \cdot n \; dS_2 = 0 + \Gamma_2$$

Since $\omega \cdot n = 0$ on the lateral surface. Thus **the circulation about a vortex tube does not vary with distance along the vortex tube.**

Theorist	8	Pointing to:	A [Kelvin's Th.]
Reflector	6		B [Kelvin's Th.]
Background	6		

F

An alternative interpretation of the surface integral circulation equation is illustrated in the following figure , showing a finite segment of a vortex tube, i.e. a volume whose lateral surface is tangent to vortex lines and whose end surfaces is normal to them, similar to a stream tube formed about streamlines.

Theorist	4	Pointing to:	D [Circulation]
Reflector	9		
Background	4		

C.2 Step by Step Retrieval Process

Circulation	A	B	C	D	E
Theorist	7	9	6	3	8
Reflector	4	3	8	9	6
Difficulty	5	6	4	3	6
	B[C]	C[C]	D[C]	F[C]	A[KT]
		D[BACK]	E[C]	E[C]	B[KT]
		E[C]			
		F[C]			

Background Material	A	B	C	D
Theorist	6	6	6	8
Reflector	6	6	5	7
Difficulty	4	5	2	4

Examples	A	B	C
Theorist	5	4	5
Reflector	7	8	8
Difficulty	2	3	

Kelvin's Theorem	A	B	C	D	E	F	G
Theorist	2	4	4	2	7	9	6
Reflector	8	8	8	8	7	4	9
Difficulty	1	7	4	1	5	6	5
	B[KT]	A[BACK]	D[KT]	E[KT]	F[KT]	G[KT]	A[V]
	A[BACK]	C[BACK]	E[KT]	G[KT]	G[KT]	A[V]	A[SDB]
	C[BACK]	C[KT]	F[KT]		A[V]	A[SDB]	
		D[KT]			A[SDB]		
		E[KT]					
		F[KT]					
		G[KT]					

Circulation	A	B	C	D	E
Theorist	7	9	6	3	8
Reflector	4	3	8	9	6
Difficulty	5	6	4	3	6
	B[C]	C[C]	D[C]	F[C]	A[KT]
		D[BACK]	E[C]	E[C]	B[KT]
		E[C]			
		F[C]			

Background Material	A	B	C	D
Theorist	6	6	6	8
Reflector	6	6	5	7
Difficulty	4	5	2	4

Examples	A	B	C
Theorist	5	4	5
Reflector	7	8	8
Difficulty	2	3	

Kelvin's Theorem	A	B	C	D	E	F	G
Theorist	2	4	4	2	7	9	6
Reflector	8	8	8	8	7	4	9
Difficulty	1	7	4	1	5	6	5
	B[KT]	A[BACK]	D[KT]	E[KT]	F[KT]	G[KT]	A[V]
	A[BACK]	C[BACK]	E[KT]	G[KT]	G[KT]	A[V]	A[SDB]
	C[BACK]	C[KT]	F[KT]		A[V]	A[SDB]	
		D[KT]			A[SDB]		
		E[KT]					
		F[KT]					
		G[KT]					

Appendix D

Raw Data

D.1 Background Knowledge

Table D.1

Range: 0 to 3

D.2 Learning Styles

Table D.2

The ranges for categorizing learning styles are:

VS: Very Strong

S: Strong

M: Moderate

L: Low

VL: Very Low

Dynamics	Fluids	Calculus	Vector Analysis	Differential Eqts
2	1	1	2	0
2	2	1	1	0
1	2	2	1	0
2	2	0	2	0
1	2	0	3	0
1	2	0	3	0
2	3	1	2	0
2	3	1	3	0
1	2	3	3	0
2	2	3	2	0
3	2	2	2	1
2	2	1	2	3
2	1	1	3	3
1	3	1	3	3
1	2	2	3	3
3	2	1	2	3
2	2	2	2	3
1	2	2	3	3
1	2	3	3	3
2	3	1	3	3
2	2	2	3	3
2	2	2	3	3
1	3	3	3	3
2	2	3	3	3
2	2	3	3	3
2	2	3	3	3

Table D.1: Background Data

Activist	Reflector	Theorist	Pragmatist
VS	VS	VS	VS
VS	M	VS	VS
M	VS	VS	VS
M	VS	VS	VS
M	VS	VS	VS
S	VS	L	L
M	M	S	L
S	M	M	M
M	S	S	L
VS	M	M	M
M	S	VS	M
VS	M	M	M
M	VL	L	L
S	VS	VS	M
S	M	L	M
L	VS	VS	S
M	VL	L	L
M	S	VS	M
S	VS	S	L
VS	M	M	L
M	S	VS	VS
VS	S	VS	S
M	VS	M	S
M	M	S	L
M	M	S	VS
S	VS	VS	S

Table D.2: Learning Styles Data

D.3 Mid-Semester Satisfaction Survey

Table D.3

Rating of 1 is very poor while a 7 is excellent

Primary Instr	Instr 2	Instr 3	Subject Rating	Hours on HW
3	n	n	2	n
3	5	6	2	8
3	6	6	3	8
4	5	5	4	3
4	6	5	4	11
6	6	7	5	6
6	4	4	5	10
5	5	5	5	4
3	4	5	5	10
6	6	6	6	4
7	5	5	6	10
7	5	5	7	6
7	7	7	7	10
7	7	7	7	6
4	6	6	4	7
7	6	6	6	6
7	5	6	6	10
6	5	5	6	5
7	5	5	7	20
2	6	6	2	11
3	4	4	2	8
2	6	5	3	6
3	5	4	3	12
5	4	5	4	15
5	6	6	4	10
6	6	6	5	10
7	6	6	6	15
6	7	7	6	13
5	5	4	4	7
6	5	n	n	n

Table D.3: Satisfaction Survey

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