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Using Computers in Fluids Engineering Education

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USING COMPUTERS IN FLUIDS ENGINEERING EDUCATION

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ABSTRACT

Three approaches for using computers to improve basic fluids engineering education are presented. The use of computational fluid dynamics solutions to fundamental flow problems is discussed. The use of interactive, highly graphical software which operates on either a modern workstation or personal computer is highlighted. And finally, the development of "textbooks" and teaching aids which are used and distributed on the World Wide Web is described. Arguments for and against this technology as applied to undergraduate education are also discussed.

INTRODUCTION

The use of personal computers and workstations in undergraduate fluids engineering education is a relatively recent development. The earliest efforts (Koening and Hodge, 1993; Fox and McDonald, 1992; and Mattingly, *et.al.*, 1987) centered around the use of software developed for personal computers. With these packages, students type input conditions at the keyboard and are presented with principally numerical output. The XFOIL program of Drela (1989) was one of the first efforts to use graphical output from early mini computers. As the mini computer evolved into the workstation, and the personal computer was developed, the operating system and output from these machines became more graphical and visual. Vision is the most perceptive sense used in education which makes the computer particularly well suited for fluids education. Recent efforts by Torella (1994) and Benson (1994, 1995a, and 1995b) have included a graphical user interface (GUI) to enhance the interaction between the student and the computer. With these packages, students use a mouse and keyboard to vary input conditions and receive principally graphical output. Most recently, Reed and Afjeh (1997) and Devenport and Mason (1998) have developed software packages which execute on the World Wide Web and are accessed by a personal computer using a browser. An excellent listing of educational software for fluids engineering students has been created by Mason and Crisafulli (1995).

Computational fluid dynamics (CFD) is taught at most major universities as part of a fluids engineering education. CFD is normally introduced to graduate students, Briley and Hodge (1995), and Lee, Diao, and Green (1995), for example, but may soon be included in some undergraduate studies. The chief argument for introducing CFD to undergraduates is that most fluids engineering graduates will be required to perform a CFD analysis sometime in their career. CFD results are a function of many factors, including the algorithm used, the number and distribution of grid points, and the turbulence model. To perform a meaningful CFD analysis, the student must have some knowledge and experience in all of these factors. Therefore, the subject

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Figure 1. CFD RESULTS FOR KARMAN VORTEX STREET

should be introduced in the undergraduate curriculum. The counter argument is that the undergraduate curriculum is already time limited, and the time is better spent learning fluid dynamics than computational fluid dynamics. To be able to recognize a bad CFD answer, a fluids engineer must have a thorough knowledge of fluid dynamics. Whether CFD is taught to undergraduates or not, CFD may have a place in undergraduate studies, as discussed below.

This paper will discuss educational software tools developed by the author in the last five years and intended as supplements for laboratory or lecture courses. The programs are designed to act like a desk top laboratory which the student uses to develop a feel and an understanding of fluid mechanics. But unlike normal laboratories, the student can use these tools as often and whenever one pleases, with little supervision, no physical danger, and at little expense. When incorporated into a lecture course, the tools can be used for homework exercises which consider many different configurations and that are otherwise too numerically intensive for a student to perform in a reasonable amount of time. The development and distribution of this software has been supported by the Learning Technologies Project of the High Performance Computing and Communications Program within NASA. The main objective in this effort is research; to find out what can be done with high performance computers and workstations. The source for all the software is in the public domain and may be further developed into commercial packages.

CFD RESULTS

Since the advent of the supercomputer, many highly detailed three dimensional flow calculations have been performed and the results presented at technical meetings using computer graphics or video tape. Because the two processes of producing the results and analyzing the results are separate, an undergraduate can study the basic physics of certain flow problems without first learning all of the intricacies of CFD to produce the results. The flow fields can be computed by a CFD expert. All that is required for student analysis of CFD results is a workstation, a graphics package, the computed data sets, and some experience with the software and hardware. The hardware and software issues are constantly evolving, but most universities currently have access to graphics computers and graphics packages. Finding the data sets to analyze can be a much more serious problem. The problem can be solved on an individual basis by professors preparing the data sets for the student, or by finding available data sets through a literature search or an Internet broadcast. The problem can also be solved through a group effort. Through the sponsorship of a central agency (professional society or government lab), CFD professionals can compute basic fluid mechanics flow fields and make the results available to the educational community. The selection of an appropriate problem for study can be provided by the user community. The results of the fundamental flow calculations can also be provided as video tapes for classroom use.

To demonstrate some of the possibilities of using CFD results for fluids engineering education, a video has been prepared which shows in great detail the periodic vortex shedding from a circular cylinder, the Karman vortex street. Figure 1. shows a still picture from the video. The calculation of the flow field was performed by Kim and Benson (1992) as part of a code development and validation study. The flow is incompressible, at Reynolds number of 100 based on free stream velocity and cylinder diameter and the calculated Strouhal number is .16. The video was prepared at the NASA Lewis

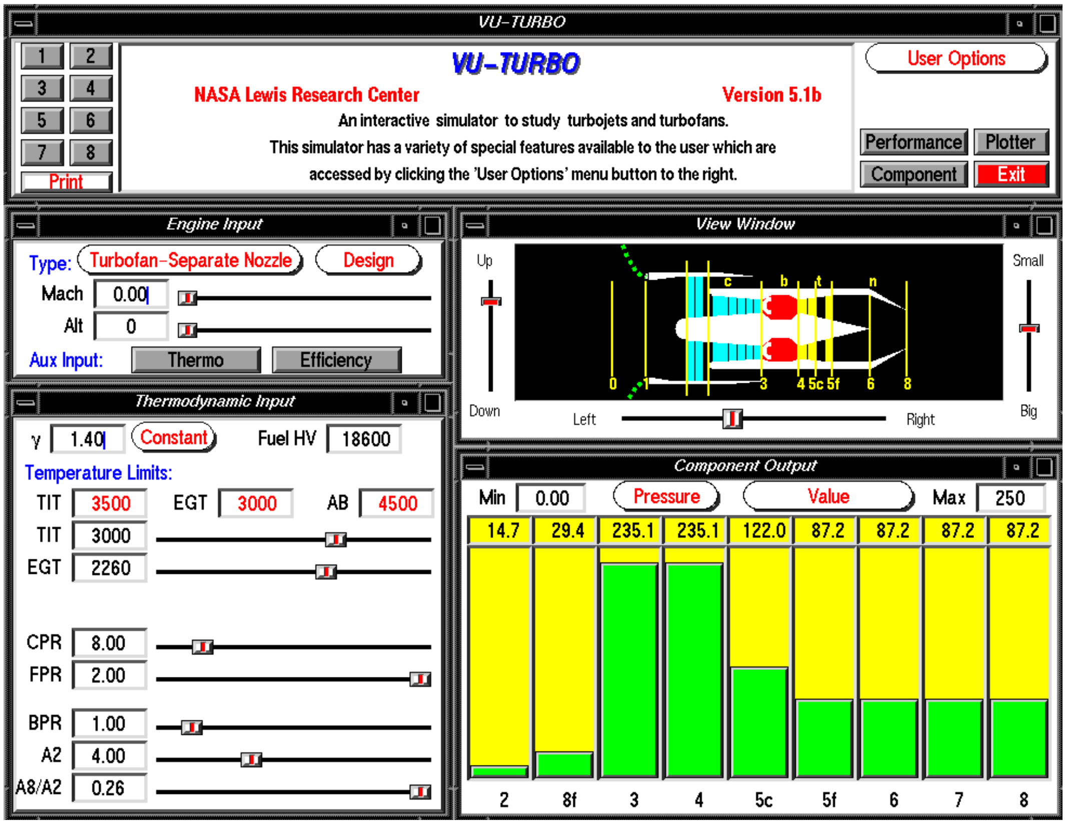

Figure 2. VU-TURBO INTERACTIVE FLOW SOLVER

Graphics and Visualization Laboratory using FAST, the Flow Analysis Software Toolkit, (Walatka *et.al.* 1994). This flow field is time dependent and the video allows the student to visualize the flow field changing with time. The video presents the same flow field in several different ways; velocity vectors, streamlines, particle traces, color-tagged particles, vorticity contours, and injected fluids. Each of the different representations present the viewer with information not available in the other representations. For instance, the particle traces shown in the figure demonstrate the formation of the top and bottom alternately shed vortices. In the video, the mixing of the flow at the rear of the cylinder is quite apparent. Color is used extensively in the video to highlight various features. Combining all of the different representations, the student can come to a better intuitive understanding of this physical process than is available from any one presentation, or from a textbook picture.

INTERACTIVE SOFTWARE

Interactive educational computer software can be used to involve the student in the learning process. Six interactive packages, five for Unix based workstations and one for Windows based personal computer, have been produced at NASA Lewis which demonstrate various flow problems encountered in an undergraduate engineering curriculum. The programs perform classic one- or two-dimensional analysis of (1) compressible flow past a ramp, (2) flow through a supersonic external or mixed compression inlet, (3) flow through subsonic wind tunnel, (4) flow through a turbojet or turbofan engine, (5) flow past a Kutta-Joukowski airfoil, and (6) flow past a spinning cylinder. Figure 2 shows a screen dump of the Unix based Visual Undergraduate program for TURBOjets (VU-TURBO, Benson, 1996), while Figure 3 shows a screen dump of the PC Windows program FoilSim. All six programs are built around a graphical user interface; as the input conditions are changed, the package computes the new out-

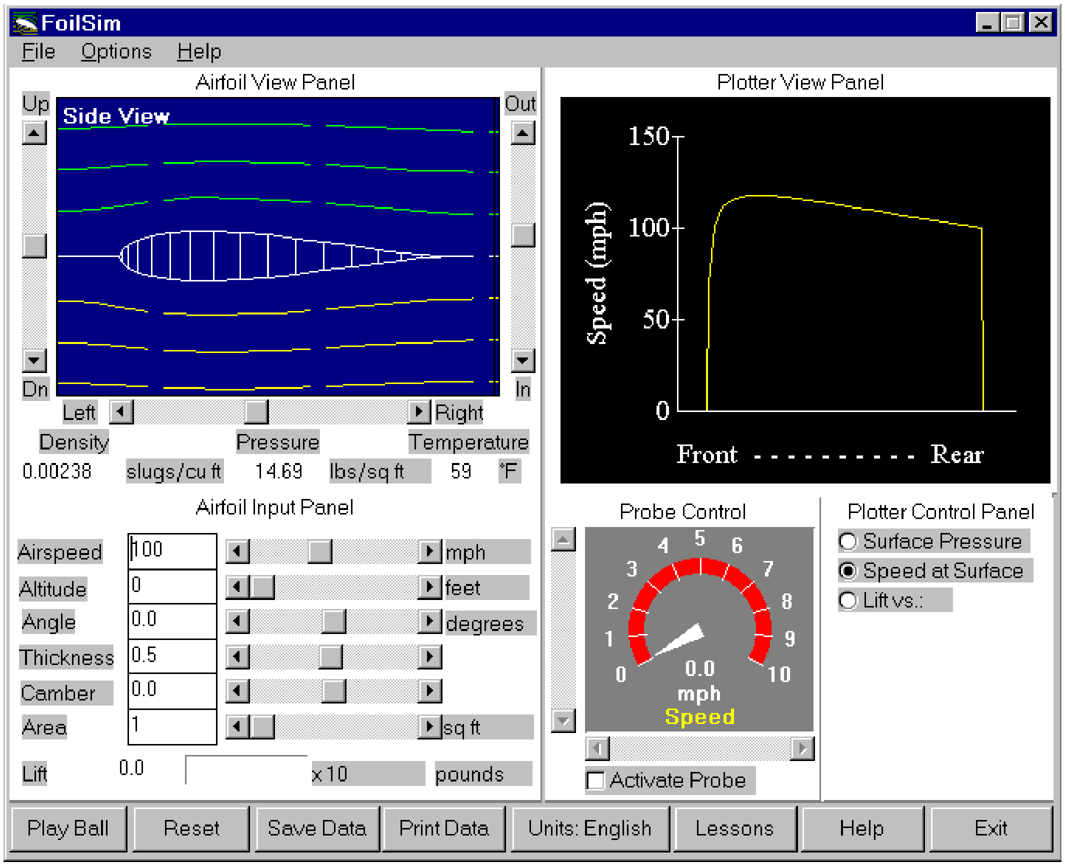

Figure 3. FOILSIM EDUCATIONAL SOFTWARE

put conditions and displays the change graphically and numerically in the output windows. The programs provide the student with an interactive plotter to generate performance curves, on-line help, and lessons prepared by the teacher which list questions for the student to answer using the program.

A guiding principal in the development of these educational tools is to do more than just present answers to problems; it is to involve the student in the learning process by having the student work with the package to achieve a result. Considering Figure 2 as an example, the student can use this package to design or analyze a turbojet, a turbojet with afterburner, or a two spool turbofan engine. The student can select the design flight conditions (Mach number and altitude) and set the appropriate design parameters (turbine inlet temperature, compressor pressure ratio, bypass ratio, etc.) using either sliders or type-in boxes. As the design parameters are changed, the output screens on the right shows the variation in pressure and temperature throughout the engine and the change in the configuration of the engine. Additional output screens show performance parameters, such as engine pressure and temperature ratio, thrust and fuel consumption. Through these visual output results and the control of the input conditions the student learns how an ideal jet engine operates and performs.

The teacher, of course, provides the student with the theory and equations governing an ideal jet engine (Brayton cycle analysis) as part of the normal course work. The teacher can now have the student compare the result of the student's hand calculations with the results from the simulator. The teacher can also have the student analyze an existing turbojet and compare the results of actual turbojet, the student's calculations, and the output from this computer tool. This introduces some of the ideas of code verification, comparison of analyses, and probably produces some interesting discussions of why the answers disagree. The program can also be used as part of a senior design class, to allow students to develop their own performance maps for a theoretical jet engine.

Figure 3 shows a screen dump of the Windows personal computer program FoilSim which was derived from the Unix program VU-FOIL (Benson, 1997). The analysis in VU-FOIL and FoilSim is the classic conformal mapping from flow around a cylinder to flow about a Joukowski airfoil with Kutta condition. VU-FOIL is intended for undergraduates and allows the student to vary all the parameters involved in the analysis; FoilSim is intended for high school students and hides most of the complex mathematics. FoilSim displays the variation of lift with velocity, altitude, angle of attack, camber, thickness and wing area. The package includes a probe which can be moved around the airfoil giving the local value of velocity or pressure and on-line lessons which describe the effects of the various parameters and poses questions which the student can answer by using the program. There is even a simulation of flow around a spinning baseball in which the student can vary the speed, spin and air density (location of the stadium) and see the resulting trajectory from the pitchers mound to home plate. The major intent of FoilSim is to increase student interest with science and math by providing an educational video game.

TEXTSITES

Another way to use computers in fluids engineering education is to provide textbooks over the World Wide Web in the form of textsites. A textsite is a group of pages written in hypertext which are prepared by an educator to teach some subject. A textsite includes information currently found in standard textbooks but presents it in a way which utilizes the power of the Web; a page can include many linked references to other pieces of information, sophisticated computer graphics, movie, or audio sequences. A textsite can be prepared by a single professor, or linked to many other professor's work around the world. The medium lends itself to the presentation of information in ways that are not available on the printed page; for instance, unsteady flows can be shown with on-line movie sequences. A textsite can be updated as required to reflect the latest area of interest in fluid mechanics.

There are some questions which need to be addressed before textsites replace textbooks. The most obvious questions involve the site: the preparer, topic, cost of operation, maintenance, updating, and cost of preparations. There are also major student (user) questions to consider: availability of resources (computer, web browser, server, ..), cost, security, and individual versus team interactions. There are surely many other questions which have not been considered. The questions and their answers can only be identified through experimentation with the technology.

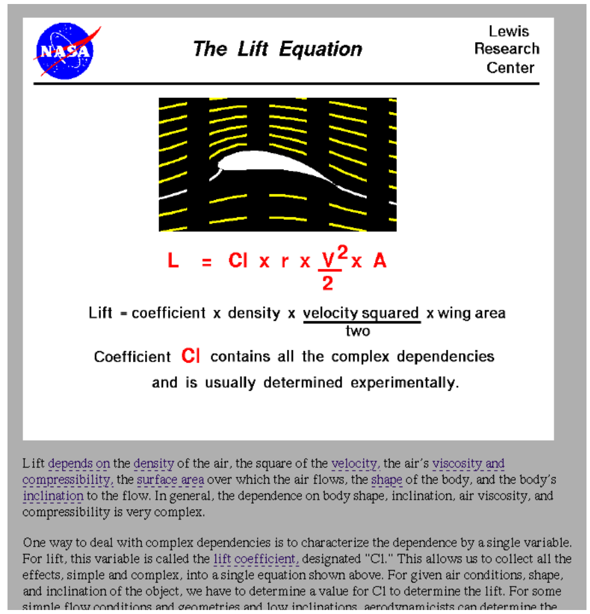

Figure 4. SAMPLE FROM AIRPLANE AERODYNAMICS WEB SITE

To explore the technology involved with creating, maintaining, and operating a textsite, the Learning Technologies Project at NASA Lewis has established a site dealing with airplane aerodynamics. The site was originally conceived to help high school teachers who acquired the FoilSim program; recognizing that high school math and science teachers are not aerodynamicists. A sample page from the site is shown on Figure 4. The teachers were interested in obtaining copies of the graphics for use in their own classrooms, so each page is arranged with a topic slide at the top and an explanation of content below. Many of the topics are interwoven; a page describing parts of an airplane links to a page describing the operation of the rudder, which links to a page on the effect of shape on lift, which links to a page on the lift force, which links to a page on wings, and so forth. On most pages, there are also links to more detailed theoretical descriptions of the information. So the user of the site can obtain a broad span of information on a topic, or obtain some depth of information on the same topic. For this site, the user starts at the highest level (full aircraft) then works down to the theory. For a fluids engineering textsite, the professor may choose to begin with the underlying theory, then work up to how various components work. A single, well-designed site can be used both ways.

SUMMARY

High speed computer mainframes, personal computers, and workstations coupled with interactive operating systems and computer graphics provide many opportunities for new techniques to teach basic fluid mechanics. This paper has presented three ways in which the new technologies can be utilized including the use of the results of CFD calculations, the use of interactive flow simulators, and the creation of web-based textbooks. Examples of these approaches have been presented along with discussion of some possible problems in their implementation.

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