Multi-level, Interactive Web-Based Simulations to Teach Fluid Mechanics at Middle School to College Levels

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Abstract: In order to introduce fundamental concepts of fluid mechanics in a stimulating way to middle- and high school students, and to provide effective teaching tools for university students in aerodynamics/fluid mechanics courses, JAVA-based interactive simulations have been created and integrated into the multi-media programs on the web. CD-ROM's are prepared for those without an internet access. The explanations and simulations are created on multiple levels of sophistication so that the users can choose the particular level best suited to their background. The subjects include unit conversion, golf ball trajectory, pendulum motion in viscous fluid, supersonic flow, and potential flow.

Keywords: multimedia, interactive, fluid flow, JAVA, simulations

1. Introduction

Partly due to its dynamic behavior and multi-dimensionality, certain concepts of fluid behavior are difficult to convey effectively in conventional class-room lectures. Students' learning experiences may be enhanced with visualizations, laboratory demonstrations and practical examples. This author has produced CD-ROM based teaching toolkits containing the experimental results of flow visualization movies made by him and his research students, as well as movies taken from an aircraft piloted by the author. [1,2]. These are available on the Syracuse university computer server for fast and wide accessibility, as well as in the form of a CD-ROM kept in the library reserve. They were also used at the engineering open house and in programs for middle schools. The project has been titled Virtual Aerospace Laboratory for Undergraduate Education (VALUE) [2] and CD-ROM's are made for both Macintosh and PC users with the Apple QuickTime plug-in.

As for the theoretical concepts in fluid mechanics covered in the lectures, the author also has prepared simulation programs for classroom demonstration and for homework assignments. Recent advances in Web technology, in particular programming in JAVA, solved these problems of updating, compatibility and accessibility. An additional merit is that the program itself resides with the original server, rather than being distributed.

This author has taught on both undergraduate and graduate levels as well as to selected middle-school students. It has been a challenge to explain various concepts to different grade groups in easy terms but with technical accuracy. There have been numerous instances in author's field, aerodynamics, in which many phenomena have been explained incorrectly or in an oversimplified manner to the general public and to school children.

A project has been initiated to introduce accurate numerical simulations for wide accessibility. This has been developed as part of a larger joint project involving Departments of Physics and Engineering at both Syracuse University and Cornell University. The project is to introduce various simulations through the internet to K-12 levels on multiple levels of complexity. Information and simulations in different fields can be found at http://simscience.org. For those without an internet access, and to keep some copyright material under control, CD-ROM is a valuable alternative. This paper, however, focuses on the Fluid Flow with which the present author and his students have been involved. In the conference presentation, individual simulations are demonstrated and discussed. Issues of dissemination and utilization are also discussed.

2. Overall structure of the program and Simulations

The different levels can be accessed from the first page (http://simscience.org/fluid or its mirror site: http://www.cis.syr.edu/mame/simfluid). Beginning level is up to 6th grade, Intermediate up to 11th grade, and Advanced 11th grade and up. For college upper class use, a link to a More Advanced Level is also provided.

The site map on the intermediate level is shown in Fig. 1 as an example of the use interface (as accessed in Japan).

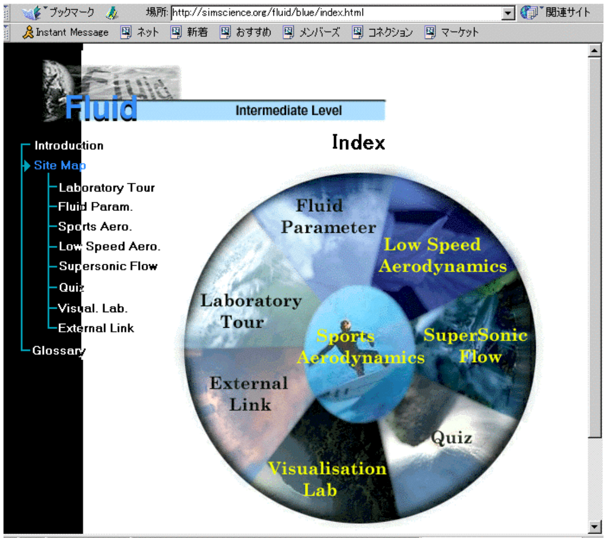

Fig. 1 Site map (Intermediate level)

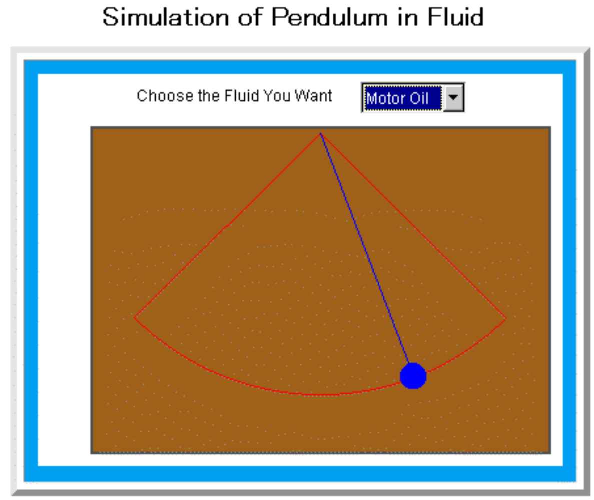

Fig. 2 Pendulum simulation

The Laboratory Tour in the beginning and intermediate levels gives an introductory tour of the wind tunnel and water channels at Syracuse University. A Quiz section utilizing CGI script asks students simple questions on the subject. The program will grade student's answers and give explanations. This was well received by middle school users during the workshop and will be enhanced further. We will view other sites more in detail below.

Fluid Parameters and Unit Conversion

This Fluid Parameters site introduces various units, not necessarily limited to fluid mechanics, and a unit conversion applet that students have found useful. In the Beginning Level, students can switch among various metric and English units in length, area, volume, mass, speed and temperature. In the Intermediate level, the definition of SI units are given and such physical quantities as density, force, energy, power, pressure are added. In the advanced level, viscosity is added.

Other significant parameters include density, pressure, temperature and speed-of-sound data in the earth's atmosphere at various altitudes. The condition of the Standard Atmosphere is displayed graphically as well as in table form and the parameter can be calculated by typing in the altitude. A Mach number calculator computes the speed of sound and the Mach number for typed-in temperature and speed. In the Advanced level, non-dimensional parameters are introduced.

Concept of Fluid Viscosity: Pendulum

Students can get the effect of viscosity of liquid and gas by trying out this pendulum simulation found in the low speed aerodynamics section. They choose the fluid and watch the pendulum swing and slow down in real time. The time-accurate integration is carried out using the drag coefficient for the particular Reynolds number at that instant. The choice of fluids is water, glycerin, motor oil, air, helium and vacuum

Sports Aerodynamics

This section, which received the Los Angels Times Launch Point Award, describes the aerodynamic effects on golf ball and baseball trajectories. The Magnus effect acting on a spinning ball is explained and simulated. The golf ball trajectory simulation is shown in Fig. 3. The student can parametrically change the forward or back spin rate, launch angle and launch velocity. On this Advance level shown, results are plotted automatically as parameters are sequentially varied. In addition a smooth ball, conventional dimpled ball or hexagonal dimpled ball can be selected.

In these simulations, published wind tunnel data [3] are incorporated and the equation of motion is integrated step by step to yield the position of the golf ball. An explanation of the simulation process is provided as a link on the advanced level. On the beginning and intermediate levels, the effect of earth gravity and lunar gravity on trajectory is shown with the image of the moon or the earth shown in the background.

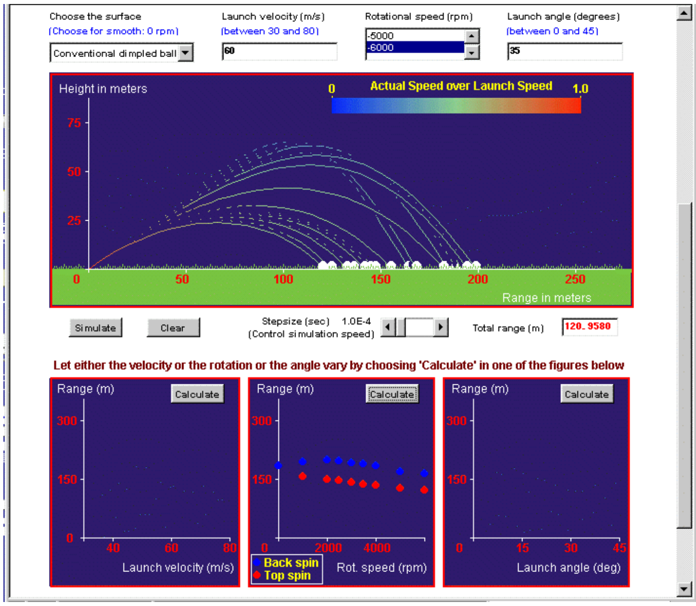

Fig. 3 Golfball tajectory simulations (Advance level)

The Baseball pitch simulation also solves the equation of motion based on the initial ball orientation and spin rate as well as wind tunnel data on lift and drag.

Flow past bluff-body such as cylinder is explained further in a related page as well as an applet showing the Magnus effect (Joukowski theorem.) If not as peaceful application, an example of rotating cylindrical bomb used to bleach dams is shown and liked to the Cracking Dam site of the joint project together with an old move clip.

Incidentally, these work on explaining available phenomena promoted new study. We have since initiated a research project which clarifies the physics behind the knuckle ball further with detailed instantaneous velocity vector field measurements [4]. Another research project of ours involves wind-tunnel flow separation and tip-vortex roll-up from a rotating flying disk [5], and we plan to incorporate the results on the web.

Superposition of elementary flows

This is an application of the potential flow theory used for analysis of low-speed flow where the effect of viscosity can be neglected. Since the equation is linearized, the solution for a particular condition can be achieved by superposing elementary solutions. Such flows are first illustrated in motion, and users can watch the particles flowing along streamlines. The flows include source, sink, and superposition of uniform flow (simulating the flow pattern over an object), vortex, solid body rotation and doublet. Figure 4 is a snapshot of the screen.

Students can proceed to actually constructing superposition of flows for example, by placing multiple vortices of various strengths at arbitrary spots, and can watch the resulting streamlines and velocity. We have decided to include this also on the beginning level, because under close guidance in the computer-cluster, middle school students enjoyed seeing flow patterns simulating aircraft vortex or flow over a cylinder. Naturally, this applet has been very useful in teaching aerodynamics for junior level undergraduate students, as well as to teach the panel method to beginning level graduate students.

It has also been incorporated into the "Tango Interactive" project demonstration (www.webwisdom.com/tagointeractive/index.html) where the instructor and students can collaborate and control in real-time the simulations from both ends.

Sound Wave Propagation and Supersonic Flow

Sound wave propagation from a moving source is simulated in animation for beginning and intermediate-level students in mind. From a sound source moving at speeds faster than the speed of sound, waves form wedge-shaped

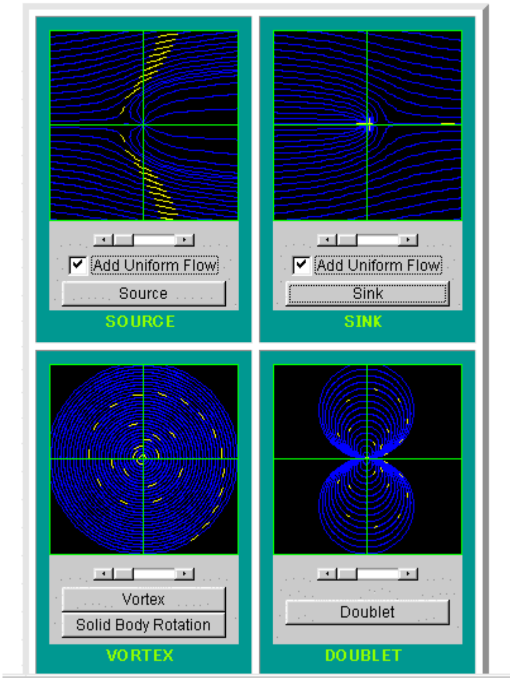

Fig. 4 Elementary flows in animation

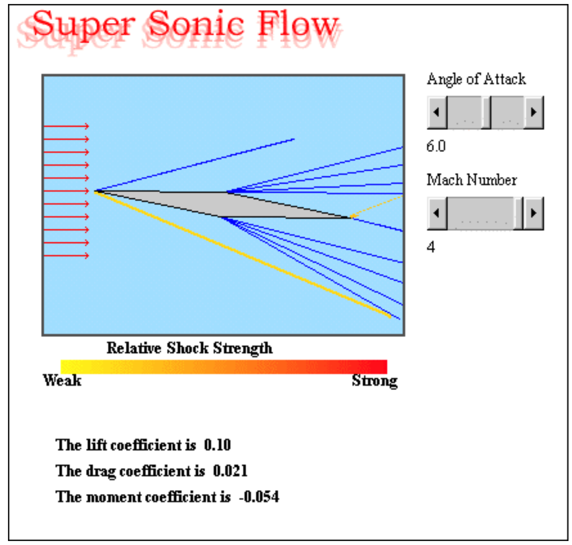

Fig. 5 Supersonic flow over a diamond airfo

envelope. Students in the Advance level can learn the concept of Mach line.

The shock-expansion method is applied in this simulation of the supersonic flow in the intermediate and advanced levels. Students can see the shock waves form the apex of a wedge-shaped body (Fig. 5.) They see how the shock wave and expansion wave patterns change as they change the incoming Mach number as well as the angle of incidence of the model. For college level, results shown on the lift, drag and pitching moment will be useful, while at a less advanced level, this and the sound propagation applet can be used to demonstrate why the SST cannot go supersonic over land and other related topics. Furthermore, the aforementioned VALUE package includes sound movies of the supersonic experiment using the same configuration, and students can compare between the simulation and the flow visualization experiment.

Project development by Students

The coding of simulations with JAVA, CGI and other appropriate language, graphics and writing of text have been carried out as a part of graduate and undergraduate independent projects under the author's direction. Students on research assistantships are given opportunities to learn the programming and fluid mechanics at the same time and to incorporate their knowledge of current and recent experience of learning the subject into teaching toolkits. Students also enjoyed explaining their work to middle school students. This has been a valuable experience for all the participants.

3. Field application and issues.

College classroom applications

The present modules have been used in the junior and senior level course in aerodynamics and aircraft dynamics as well as in the first year graduate course in fluid dynamics. Initially a PC with projection hook-up was brought into a lecture room, but recently, a well-equipped, multi-media lecture room which has been newly built in the Engineering building has been effectively utilized. Here the instructor makes a presentation on a large screen while students work under supervision on individual machines with their monitors integrated just beneath their desktops. Homework assignments are performed on or off campus. Students are asked to compare their calculation based on the theory, for example, potential flow theory, with the computer simulation. One point that was brought to our attention by some off-campus students is that their computers may have a small monitor, and their CPU and modem may be too slow to access and execute the simulation in a timely manner. One needs to keep this in mind during the program development using fast machines on campus network. On the other hand, machines elsewhere may be more advanced than that the original developer used. For example, speed of animations of potential flow and golf ball became too fast on recent machines, and the speed slider (see Figs. 3 and 4, for example) had to be later added to control the speed.

Judging from student evaluations and student usage at computer clusters, these teaching toolkits have been very effective as supplementary material as designed. They were not intended for a web-based course nor for a CD-ROM textbook. The project has been now dovetailed with a new college level project with another faculty member specializing solid-mechanics for mechanics-based courses. Naturally, the site is to be utilized first in the courses one is directly involved with. An effort will be made to make material useful to other instructors. Owing to the inherent design of web authoring, the materials are easily modified and linked to other sites to fit individual needs. For example, the present external links include an isentropic flow calculator and other applets developed by W. Devenport et al at Virginia Tech. (http://www.aoe.vt.edu/aoe3114/calc.html, http://www.engapplets.vt.edu/) and the present site is linked by other universities.

Middle- to High School Application

The site has been used in the Syracuse Science Horizon program, a summer program at Syracuse University for selected local middle school students from 40 schools in the county. Students first get introduced to the site in the computer cluster room and have hands-on simulations of the fluid flow. The program ends with a simple experiment/demonstration of the wind tunnel and water channel. The level of the material was found to be suitable for these well-motivated students, and some students were even browsing at a higher level. The overall SimScience site was also tested with 10th grade high school students at the NASA-Sharp program at Cornell. The fluid module was also well received at a workshop for middle school students at Lehigh University. These simulations and accompanying explanations have been proved to be effective as resources and as a motivator. E-mails received from individual students in the US and Europe, asking for further information, are further proof of their value.

One point of concern, however, is that when CD-R's of the SimScience project, containing membranes, fluid flow, cracking dams and crackling noise, have been mailed to local public schools with requests for feedback, the response from teachers has not been as enthusiastic as expected, and some teachers have not even tried the program. It is difficult to assess which units are better suited for K-12 education, but it can be said that the material has not been developed to be an integral part of the school curriculum. Furthermore, computers are available in schools but they may not be equipped with modern networks nor in sufficient quantities. In addition, assessment of the difficulty level of other groups' modules was not as straightforward as assessing those in one's own instructions. Unlike college applications where the developers have direct knowledge of the usage, further discussion among the group is needed on how to disseminate the material among middle- and high schools effectively and how to make and keep the material truly useful and integrated. The Instructional Design, Development and Evaluation Program at the School of Education has been recently asked to collaborate on evaluation [6.] This author also realizes that the issue of integration may have another dimension in Japan and other societies where priority is given to topics covered in entrance examinations.

4. Acknowledgements

This project was supported in part by the NSF-MRA program and the NSF-REU program in Fluid Mechanics. Contributions by following students are acknowledged and their names are listed on the web and appear together with specific applets: Menko Wisse, Mustapha Guesmia, Tosho Kiura, Samuel Hund, and Michel van Rooij.

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