Int. J. Engng Ed. Vol. 19, No. 2, pp. 305–315, 2003
Printed in Great Britain.

0949-149X/91 $3.00+0.00

On Developments in Interactive Web-based Learning Modules in a Thermal-Fluids Engineering Course*

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The main objective of this study is to investigate how the traditional lecture format in engineering education might be complemented and enhanced by computer-based teaching and learning methods. We consider the development of Web-based learning modules for 2.005 Thermal-Fluids Engineering I, a second year Mechanical Engineering course at Massachusetts Institute of Technology (MIT). These modules are the result of an initiative known as the I-Campus project which seeks to comprehensively transform the traditional education structure. The new engineering education methodologies that are introduced in this paper deal particularly with heat transfer interactions in thermal-fluids systems.

INTRODUCTION

THE WORLD-WIDE WEB provides a new means of communication between students and faculty, and hence presents an opportunity to bring new teaching techniques into the classroom. Undeniably, changes are being made in the classroom from classical teaching methods to Web-based learning environments. Many of these changes are the result of the development of technology-enabled learning interfaces in the educational environment. Web-based learning systems are flexible with multiple learning methods such as text, graphics, audio, video, animation, and simulation. The present paper offers a module format that can be used not only for other undergraduate courses but also for graduate courses. While this project focuses on improvements for residence-based education, the approaches we outline here can also be used for distance education.

Several studies of the application of computational analysis of heat transfer and fluid mechanics concepts in the classroom may be found in the literature. In the 1970s and 80s, Gosman of Imperial College developed computer-assisted courses in heat transfer and fluid flow [1]. Sparrow and Abraham at the University of Minnesota developed a thermal engineering course that uses finite element software to allow students to model complex systems [2]. Stubley and Hutchinson of the University of Waterloo studied the use of CFD in undergraduate level courses to reinforce student understanding of complex flow physics [3]. Ridwan, Yap, and Mannan of the National University of Singapore developed web portal designs for handling web-based thermal-fluids courses [4].

The Mechanical Engineering Department at MIT has undertaken an initiative known as the *I-Campus* project to develop instructional and learning paradigms that will revolutionize MIT's Undergraduate Mechanical Engineering Program. Typically, course websites have functioned as little more than online repositories for problem set solutions. The aim of this project is to leverage the course website as a supplementary teaching tool by developing new content for *2.005 Thermal-Fluids Engineering I*—a second-year course in thermodynamics, fluid mechanics, and heat and mass transfer. These materials are used by the instructor during lecture and used at home by the students is strongly encouraged.

The 2.005 course content consists of eight basic topics:

1. Thermal-Fluids Engineering: A Modern Technology
2. Energy and the First Law of Thermodynamics
3. Equilibrium and the Second Law of Thermodynamics
4. Simple Models for Thermal-Fluids Systems
5. Work Transfer Interactions in Thermal-Fluids Systems
6. Heat Transfer Modes and Thermal Resistance
7. Energy Conversion: Heat Transfer to Work Transfer
8. Open Thermal Fluid Systems.

In this paper, we discuss only the web-based learning module 'Heat Transfer Modes and Thermal Resistance' topic. Each of the web-based learning modules is divided into six sections:

- *Information*—online text and theoretical derivations.

* Accepted 2 August 2002.

- *Simulations*—Java-based simulations developed for various topics covered in the module.
- *Worked problems* – problems with complete step-by-step solutions which also employ the simulations whenever possible.
- *Exercises*—problems for the student to solve independently.
- *Real world examples* – development of models to describe real engineering systems.
- *Reference* – supplementary materials for extra study and review.

In what follows, each of the six sections is described in detail. It should be noted that these sections do not simply stand alone, but are interdependent; for example, a worked problem solution might require a simulation and hence, a direct link to this simulation is provided.

INFORMATION SECTION

This part of the module contains textbook-style derivations that go beyond what is covered in the lecture. This part examines the fundamentals of the heat transfer interactions using simulations, graphs, analytical derivations, text, and figures. At the start of the section, a linked listing of the available lectures and derivations is provided to allow a student to easily access material of interest, both text and simulations. This section covers a number of major topics such as 'modes of heat transfer,' 'thermal resistance,' 'conduction in cylindrical geometries,' etc. The text material is based on the course reference book [11]. In the web text, there are links to appropriate simulations that may be run in parallel with that text. It is also possible to run more than one simulation at the same time. For example, Fig. 1 shows a thermal conduction simulation program and a transcendental equation solver (in the two forward-most windows) running over a window containing the related text material. The hyperlinks allow the student to jump easily from the theoretical derivations to a simulation and back again.

SIMULATIONS SETION

Computer-based simulations are one of the great strengths of this new approach. Frequently, the mathematical solutions of the theory are so complicated that the physical behavior is not clear. In addition, many physical phenomena are invisible to the naked eye and, hence, the students have not developed an intuition for such phenomena. Examples of these phenomena include temperature

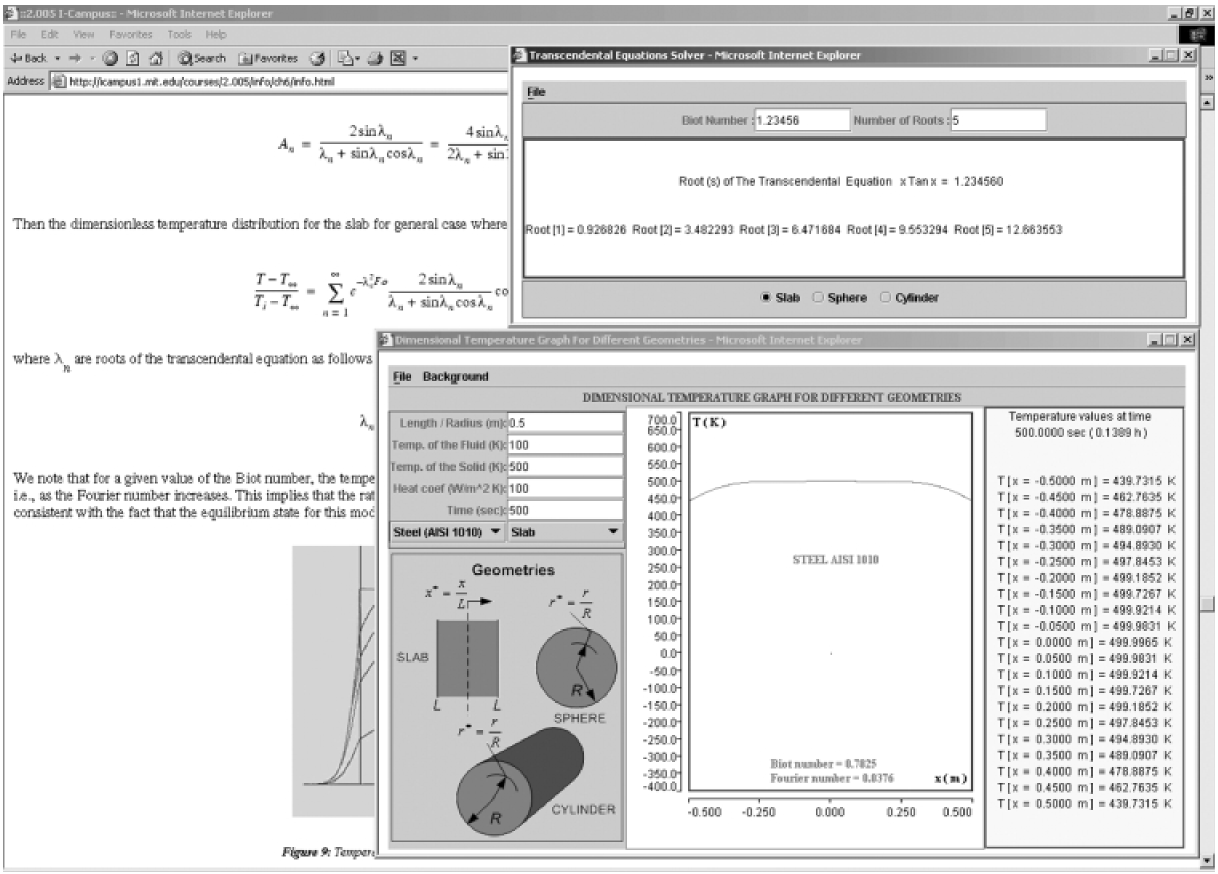

Fig. 1. The software supports the simultaneous use of text, simulation, and calculation. This screenshot shows a text window in the background that discusses heat transfer theory. The two windows in the foreground are a transcendental equation solver and a thermal simulation relevant to the text.

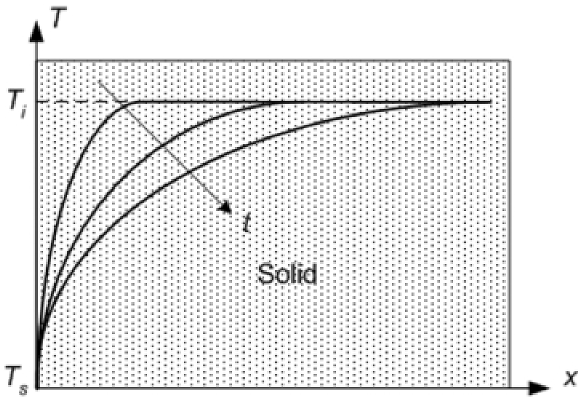

Fig. 2. Temperature history of a semi-infinite solid with a sudden change in surface temperature.

distributions, stress distributions in a beam, electric fields and magnetic fields. Computer simulations can animate these solutions and allow the students to directly investigate the effect of altering several parameters on the system. Many classical problems and physical situations lend themselves to the simulation of the underlying mathematics in a way that allows the student to grasp the fundamental concept more completely. We do not believe that the simulations should replace the theoretical discussions but they can dramatically enhance the student's intuitive understanding of the material.

The simulations developed for this module are based on the Java programming language. These simulations or 'applets' are supported and executed by the student's web browser and thus are easily integrated into any web-based learning environment.

The Heat Transfer Modes and Thermal Resistance module contains eighteen simulation programs and four calculator programs. The simulations include, for example, temperature distribution simulations for slabs, spheres, and cylinders immersed in a fluid, a convective heat transfer simulation, a surface energy pulse simulation, and a periodic variation of the surface temperature simulation. There are also simulations of the fractional energy loss versus Fourier number as well as versus Biot number and centerline temperature simulation versus Fourier number. Four calculators have been developed to allow the students to quickly calculate values that students might need for their problem sets such as Bessel functions and convective cooling coefficients.

Theoretical basis of the simulations

In the Heat Transfer Modes and Thermal Resistance module, the students are exposed to several simple and standard examples of heat transfer. These examples include the temperature evolution of a semi-infinite solid exposed to a fixed temperature on its surface (see Fig. 2) and the temperature evolution of a hot object immersed in a cold fluid bath. The shapes of the objects considered in the latter case are the slab, the cylinder and the sphere as shown in Fig. 3. Summaries of the solutions are given here to provide a background for the simulations that will be discussed later and to make it clear that the mathematical solutions of these problems are sufficiently complicated that most students do not gain significant physical insight from them.

In the solid, the temperature distribution, T, is determined by the one-dimensional heat equation:

$$\frac{\partial^2 T}{\partial x^2} = \frac{1}{\alpha}\frac{\partial T}{\partial t} \tag{1}$$

where α is the thermal diffusivity, x is the spatial coordinate and t is time. The initial temperature of the object, T_i, is assumed to be uniform. The fluid temperature far from the object, T_∞, is assumed to be constant throughout the process. The surface boundary condition on the object requires that the heat flux just inside the surface of the object matches the heat flux in the fluid just outside the surface of the object or:

$$k\left.\frac{dT}{dx}\right|_{surface} = h(T_{surface} - T_\infty) \tag{2}$$

where k is the thermal conductivity of the solid, h is the heat transfer coefficient between the solid surface and the fluid, and $T_{surface}$ is the surface temperature of the solid.

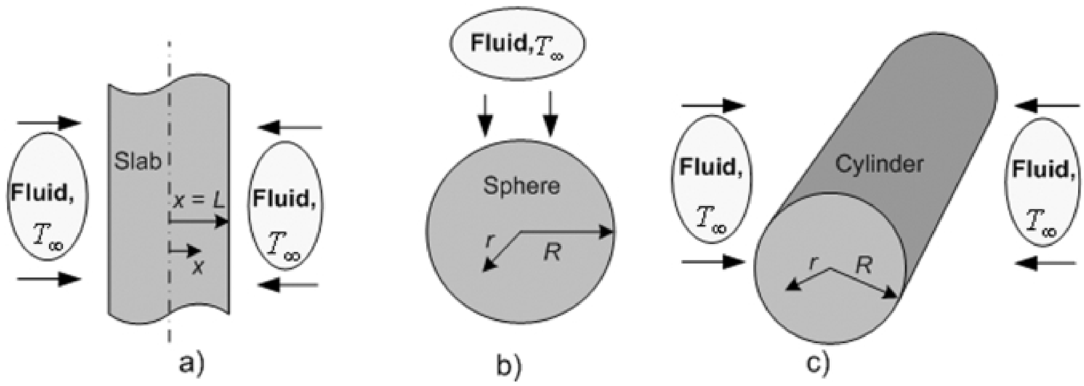

Fig. 3. Schematic representation of shapes of the objects considered in this section: slab, sphere, and infinite cylinder. In each of these cases the fluid entirely surrounds the object.

There are closed form solutions to this equation for very simple geometries. The semi-infinite solid, shown in Fig. 3, at uniform initial temperature that is suddenly exposed to a hot fluid on one surface is one of these closed form solutions. The solution is of the form:

$$\frac{T(x,t)-T_\infty}{T_i-T_\infty}=erfc(\tau) \tag{3}$$

where $\tau = x/\sqrt{4\alpha t}$ and $erfc(\tau)$ is the complementary error function defined as:

$$erfc(\tau)=1-\frac{2}{\sqrt{\pi}}\int_0^\tau e^{-u^2}\,du \tag{4}$$

In the more complicated case of an object immersed in a different temperature fluid, the solution can be written as an infinite series and a transcendental equation whose roots determine a set of parameters used in that infinite series.

For example, in the case of the slab of thickness L (a slab) shown in Fig. 3a, the series is:

$$\frac{T-T_\infty}{T_i-T_\infty}=\sum_{n=1}^{\infty} e^{-\lambda_n^2 Fo}\frac{2\sin\lambda_n}{\lambda_n+\sin\lambda_n\cos\lambda_n}\times\cos(\lambda_n x/L) \tag{5}$$

where Fo is the Fourier number $(=\alpha t/L^2)$ and x is the position within the slab (the origin is at the center of the slab). The parameters λ_n $(n=1,2,3\ldots)$ are roots of the transcendental equation:

$$\lambda_n \tan\lambda_n = Bi \tag{6}$$

where Bi is the *Biot* number $(=hL/k)$.

The temperature distribution for the case of a sphere suddenly immersed in a fluid differing in temperature, shown in Fig. 3b, can be solved in a manner analogous to the slab calculation above. The series solution is:

$$\frac{T-T_i}{T_\infty-T_i}=\sum_{n=1}^{\infty}\frac{4[\sin(\lambda_n)-\lambda_n\cos(\lambda_n)]}{2\lambda_n-\sin(2\lambda_n)}\times e^{(-\lambda_n^2 Fo)}\frac{1}{(\lambda_n r/R)}\sin(\lambda_n r/R) \tag{7}$$

where r is the radial coordinate, R is the radius of the sphere and the Fourier number, Fo, is defined as $\alpha t/R^2$. In this case the parameters, λ_n, are defined by the roots of the equation:

$$1-\lambda_n\cot\lambda_n = Bi, \tag{8}$$

where the *Biot* number is based on the radius of the sphere (hR/k).

Similarly, in the case of the infinite cylinder shown in Fig. 3c, the solution is:

$$\frac{T-T_i}{T_\infty-T_i}=\sum_{n=1}^{\infty}\frac{2J_1(\lambda_n)}{\lambda_n[J_0^2(\lambda_n)+J_1^2(\lambda_n)]}\times e^{(-\lambda_n^2 Fo)}J_0(\lambda_n r/R) \tag{9}$$

where J_0 and J_0 are *Bessel* functions of the first kind, of orders 0 and 1, respectively. The *Fo* and *Bi* numbers are based on the radius of the cylinder and the values of the parameters λ_n are determined using:

$$\lambda_n J_1(\lambda_n) - Bi\,J_0(\lambda_n) = 0. \tag{10}$$

A general form of the solution for the slab, infinite cylinder, and sphere geometries may be written:

$$\frac{T-T_i}{T_\infty-T_i}=\sum_{n=1}^{\infty}A_n e^{-\lambda_n^2 Fo}F_n(\lambda_n,\eta) \tag{11}$$

where the appropriate expressions for A_n and F_n are given in Table 1 [11, 12, and 13] and η is characteristic length.

Clearly, in all the solutions presented here (Equations 5, 7, and 9), the behavior of the temperature field as a function of time in the solid is not transparent to the uninitiated. Simulations can be employed to animate the temperature field for the student and give the student a visual tool to enhance his or her understanding. It is in a niche like this one that the simulations have great value.

The fraction of the total energy change can be calculated for the slab using the first law of thermodynamics and the temperature distribution for the slab (Equation 5). The result is:

$$\Phi = 1-\sum_{n=1}^{\infty}e^{-\lambda_n^2 Fo}\frac{2\sin\lambda_n}{\lambda_n+\sin\lambda_n\cos\lambda_n}\frac{\sin\lambda_n}{\lambda_n} \tag{12}$$

The fractional energy loss can be expressed in a

Table 1. The constants A_n, B_n and the function F_n for the transient response of slabs, infinite cylinders, and spheres.

	A_n	B_n	$F_n(\lambda_n\,\eta)$
Slab	$\dfrac{2\sin\lambda_n}{\lambda_n+\sin\lambda_n\cos\lambda_n}$	$\dfrac{\sin\lambda_n}{\lambda_n}$	$\cos(\lambda_n x/L)$
Cylinder	$\dfrac{2J_1(\lambda_n)}{\lambda_n(J_0^2(\lambda_n)+J_1^2(\lambda_n))}$	$2\dfrac{J_1(\lambda_n)}{\lambda_n}$	$J_0(\lambda_n r/R)$
Sphere	$2\dfrac{\sin\lambda_n-\lambda_n\cos\lambda_n}{\lambda_n-\sin\lambda_n\cos\lambda_n}$	$3\dfrac{\sin\lambda_n-\lambda_n\cos\lambda_n}{\lambda_n^3}$	$\dfrac{\sin(\lambda_n r/R)}{\lambda_n(r/R)}$

generalized form for the slab, infinite cylinder, and sphere geometries as:

$$\Phi = 1 - \sum_{n=1}^{\infty} A_{\rm n}\, e^{-\lambda_n^2 Fo} B_{\rm n} \tag{13}$$

where A_n and B_n are given in Table 1.

DESCRIPTIONS OF THE SIMULATIONS

In what follows, the simulation programs that animate the results described above are presented with images of their graphical interfaces. Following this, a series of short descriptions of the many other simulations that are part of the Heat Transfer Modes and Thermal Resistance module is given.

Temperature distribution simulation for slabs, spheres, and infinite cylinders

The graphical interface for the simulation program that calculates the temperature distribution in a slab, infinite cylinder or sphere as a function of time is shown in Fig. 4. Once again, the object in question is assumed to be at a uniform initial temperature and then is plunged into a liquid bath at a different temperature at $t = 0$ s. The simulation calculates the temperature profile evolution subsequent to $t = 0$ s. This program calculates the temperature values by using the general formula for slabs (Equation 3), for spheres (Equation 5), and for cylinders (Equation 8).

The input/output window for this simulation is divided into several parts. The physical parameters part of the display (the upper left-hand corner of Fig. 4) allows the student to input the characteristic dimension of the object, the initial temperatures of the solid and the liquid, and the heat transfer coefficient between the solid and the liquid. A pop-up library of twenty three materials can be called on by pressing the 'aluminum' button in Fig. 4. In addition, this library contains a custom entry where the student can specify the thermal conductivity, the density and specific heat capacity of the solid object.

The slab, cylinder, or sphere case can be chosen by pointing and clicking on the appropriate icon on the lower left-hand side of the window. Since the sums in the equations contain an infinite number of terms, the user must specify the number of terms used to calculate the temperature distribution in the 'number of terms' box. The simulation speed can be varied using the slider at the top of the screen.

In Fig. 4, the simulation displays two plots of the temperature versus position, one in non-dimensional form and the other in dimensional form. Each of these plots has three traces associated with them. One trace corresponds to the case specified by the physical parameters (the program shows this trace in red). In the example shown the

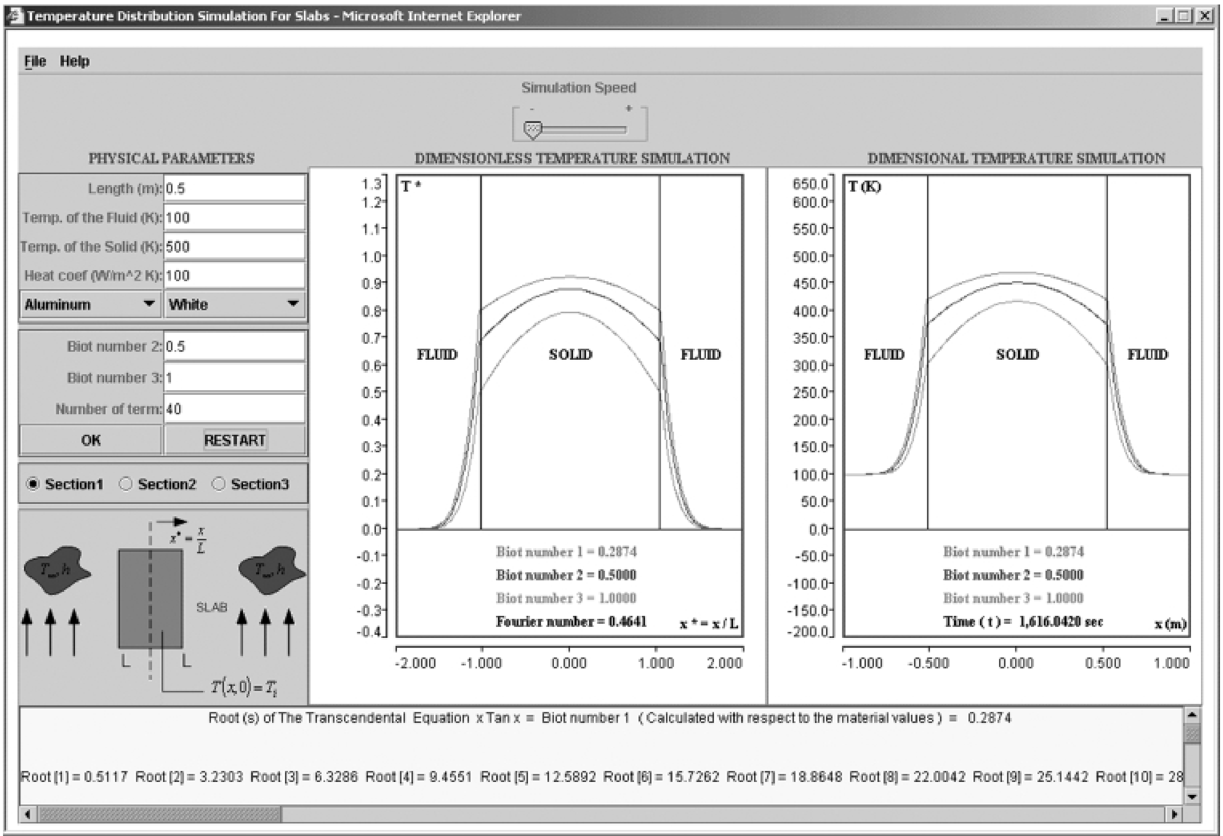

Fig. 4. Temperature distribution simulation for slabs (Section 1).

'physical parameter' trace is the top trace corresponding to a Biot number of 0.2874 (Biot number 1). The other two traces correspond to Biot number 2 and Biot number 3 specified by the user in the corresponding input box on the left-side of Fig. 4. This feature allows the student to compare the spatial and temporal response of up to three different materials.

The 'Section 1, Section 2, and Section 3' menu located above the slab, cylinder, and sphere icons allows the student to choose the output graphs of the simulation. The 'Section 1' option shown in Fig. 4 consists of plots of the spatial temperature distribution that evolve with time. The output is essentially a 'movie' of the spatial temperature distribution with a time (or Fourier number) index.

The 'Section 2' option is like but replaces the dimensionless temperature graph with a dimensional graph of the centerline temperature.

The 'Section 3' option consists of a dimensionless graph of the centerline temperature versus time and a spatial temperature distribution movie, convenient for the small Biot number case. As the temperature distribution in the solid is uniform and the numerical solution is not conveniently solved using Equations 5–10, a lumped parameter model is used.

There is a weakness in the simulation program described above. The user cannot specify the time at which the temperature distribution is calculated. This becomes an issue when the student must develop a quantitative answer in a problem set. The input/output window of a program that satisfies this need is shown in the bottom right of Fig. 1. The physical parameters as well as the time of the calculated temperature distribution are specified by the user in the upper left-hand corner of the window. Pop-up menus allow the user to choose from a library of materials and geometries. The temperature distribution for the specified time is displayed graphically and as an array of temperatures in the two output fields of the window.

Constant surface temperature simulation

This is the first of several programs that simulate the temperature evolution in a semi-infinite solid. In this simulation, a semi-infinite solid is assumed to be at uniform temperature initially. At time $t = 0$ s the surface temperature of the semi-infinite solid is set to some new temperature. The simulation calculates the time evolution of the temperature distribution. This semi-infinite solid model physically corresponds to a thick wall that is suddenly exposed to a fluid with a very large heat transfer coefficient between the surface and the fluid.

Constant heat flux temperature graph

The constant heat flux temperature graph is similar to the constant surface temperature simulation described above except that the surface boundary condition is a constant heat flux boundary condition. This model could be used for the case of constant laser irradiation of a surface.

Surface energy pulse temperature simulation

The surface energy pulse temperature simulation simulates the temperature distribution in a semi-infinite block after a pulse of thermal energy is suddenly deposited on the surface. The total energy deposited by the pulse is an input parameter for this simulation. This simulation can be used to model the effect of a laser pulse on the surface of a solid.

Convective heat transfer temperature simulation

The convective heat transfer temperature simulation calculates the temperature distribution in a semi-infinite solid as a function of time. In this case, the semi-infinite solid is assumed to be at uniform initial temperature at time *t\eqalignno* {$= 0$ s where is it suddenly exposed to a fluid at temperature T_∞. The heat transfer coefficient, h_c, between the solid surface and the fluid is specified by the user.

Periodic variation of the surface temperature simulation

In this simulation, the surface temperature of the semi-infinite solid is varied sinusoidally and the temporal and spatial response of the temperature field in the solid is calculated and plotted. A physical system that can be modeled by this simulation is the seasonal and diurnal variations of the temperature of the earth's surface.

Temperature distribution simulation of two semi-infinite solids in simple thermal communication

This simulation calculates the evolution of the temperature distribution of two semi-infinite blocks whose surfaces are brought into thermal contact at $t = 0$ s. Each of the blocks is initially at uniform temperature. The initial temperature of each solid is specified by the user using the simulation as shown below in Fig. 5.

Transcendental equations solver

The transcendental equation solver is the first of a series of 'calculator' programs for the student. On occasion, the students are asked to determine by hand several terms in the series solutions for the temperature distributions. This program calculates the roots of the transcendental equations that determine the parameters, λ_n, in Equations 6, 8, and 10.

Bessel functions calculator

The Bessel functions are usually not discussed at length in an undergraduate course. However Bessel functions do appear in the solution of the cylindrical geometry discussed above (Equations 9 and 10). Hence, an appendix discussing Bessel functions and a calculator is included in the

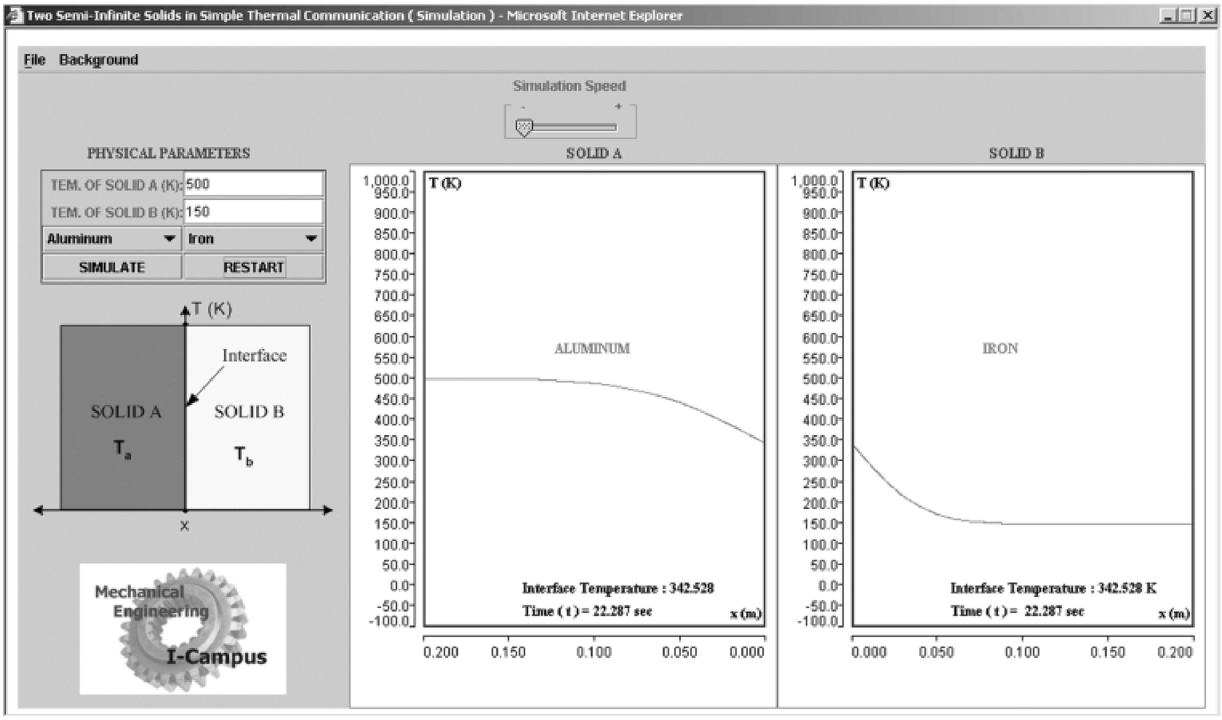

Fig. 5. Two-infinite solids in simple thermal communication.

module. The calculator determines values for Bessel functions of the first and second kind and modified Bessel functions for orders zero and one.

Error function calculator

This calculator calculates the complementary error function (Equation 4) necessary for semi-infinite solid model calculations.

Convective cooling constants calculator

The series solutions (Equations 5, 7, and 9) converges rapidly for long times. For $Fo > 0.2$, only the first term of series needs to be retained for 98% accuracy. However, in many engineering systems, we are interested in very short times ($\mathrm{Fo} < 0.2$) for which the one-term approximation is insufficiently accurate. This program allows the user to calculate the constants A_n, B_n, and F_n to determine the convective cooling of slabs, spheres, and cylinder geometries using the general formulation given as Equations 11 and 13.

Heat conduction chart simulations

In the heat transfer and thermodynamics literature, graphical representations illustrate the functional dependence of thermodynamic quantities by variation of an index parameter such as the Fourier or Biot number. Two cases which typically are employed are the fractional energy loss and the centerline temperature for the slab, cylinder, and sphere geometries. The 'chart simulations' we have developed have two advantages over the graphical representations found in texts. First, the user is not limited by the given values; he or she may choose a specific value of interest and this value may have additional significant figures over those available in the textbook chart, for example 0.5 versus 0.533. Second, the user may compare between the three different geometries on the same plot, rather than a separate plot for each of the geometries.

These chart simulations cover three cases:

1. Fractional energy loss simulation versus Fourier number, *Fo* (Fig. 6).
2. Fractional energy loss simulation versus Biot number, *Bi*.
3. Centerline temperature simulation versus Fourier number, *Fo* by unsteady thermal conduction (Fig. 7).

Temperature distribution simulation for different initial functions

This simulation allows the user to simulate the temporal evolution of a temperature distribution for several different initial spatial temperature distributions. These initial spatial distributions, $T(x)$, include $T(x) = \{1, x^2, \sin(x), \sin(x)\cos(x), x\sin(10x)\}$. In most undergraduate treatments of the heat conduction equation the students are not exposed to the time evolution of temperature distributions in a solid. Through the use of the simulation, students are able to see that high-spatial-frequency components of the temperature field are quickly 'smoothed-out' by unsteady thermal conduction.

WORKED PROBLEMS SECTION

These problems focus on the transient analysis of heat transfer between a solid and a fluid

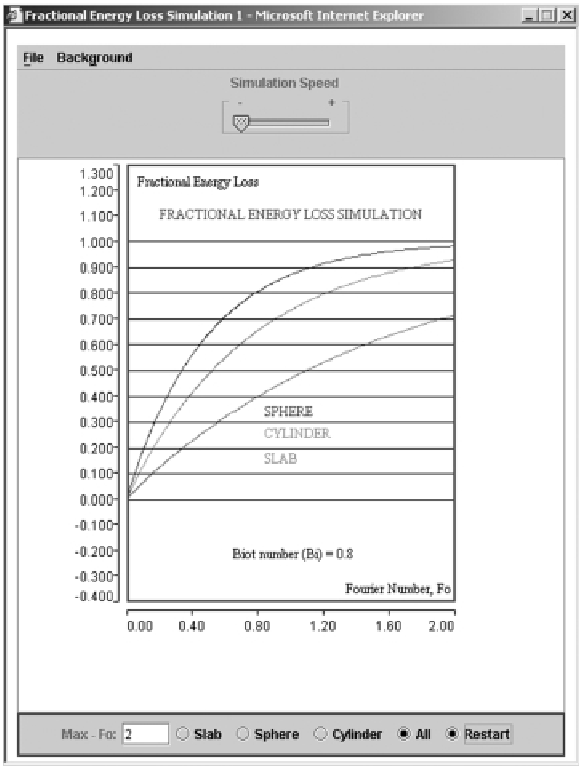

Fig. 6. Fractional energy loss simulation versus Fourier number. The student is able to compare between the different geometries side by side and for a specific value of interest.

environment and transient heat transfer to a semi-infinite solid. The solutions to these problems include an analytical solution followed by a solution that uses the appropriate simulation program. In the worked problem section, shown in Fig. 8, the student is instructed on the use of the simulation program and interesting features of the solution that may not be apparent in the analytical solution are identified and discussed.

EXERCISES

The exercise section of the module contains several problems designed to test understanding of the topic. The module includes simulations and calculators such as temperature distribution simulations for different geometries, Bessel functions calculator, transcendental equation solver, etc. connected via hyperlinks in order to help to the students solve the exercises included in the problem statements.

REAL WORLD EXAMPLES

The ability to model 'real' engineering systems and devices is an important skill that is often underdeveloped in typical engineering courses due to the vast amounts of technical information instructors must convey. The Real World Examples Section is designed to bolster students' skill in this area by walking the student through the modeling process for a few different cases relevant to the material covered in the module. Another critical area these examples address is the ability to make appropriate approximations. It is common for a student to become so caught up in the

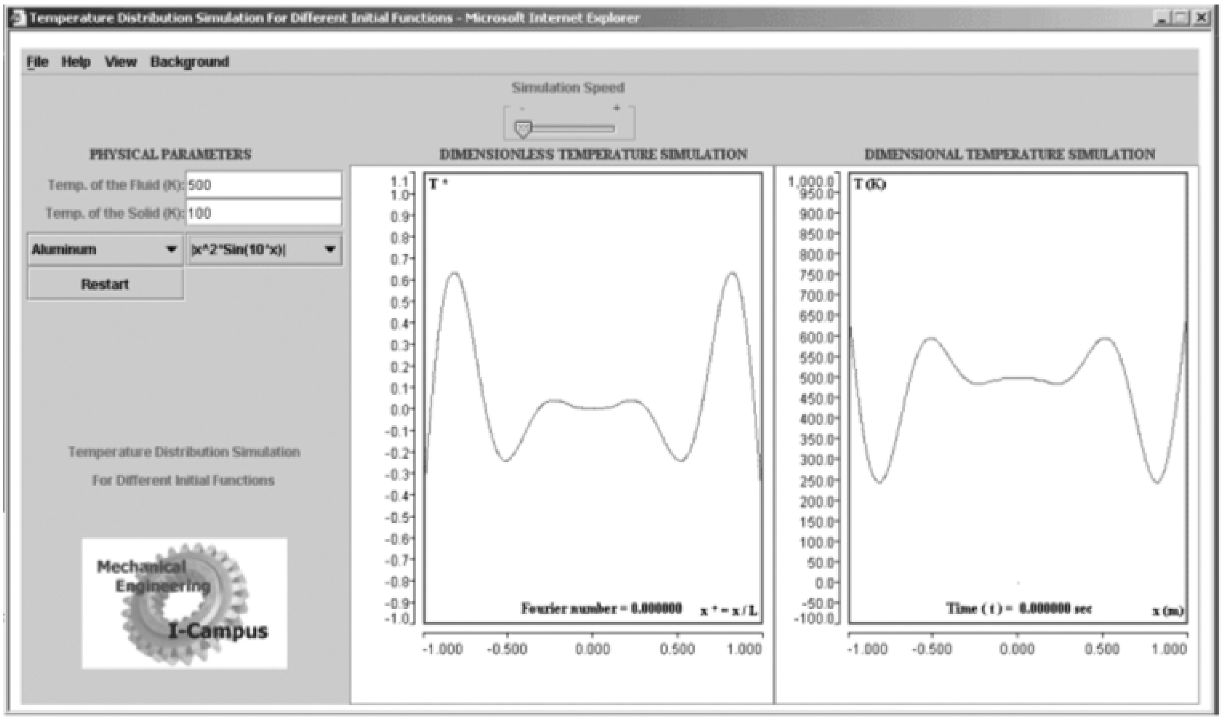

Fig. 7. Temperature distribution simulation for different initial conditions shown with an initial temperature distribution of $T(x) = |x^2 \sin(10x)|$.

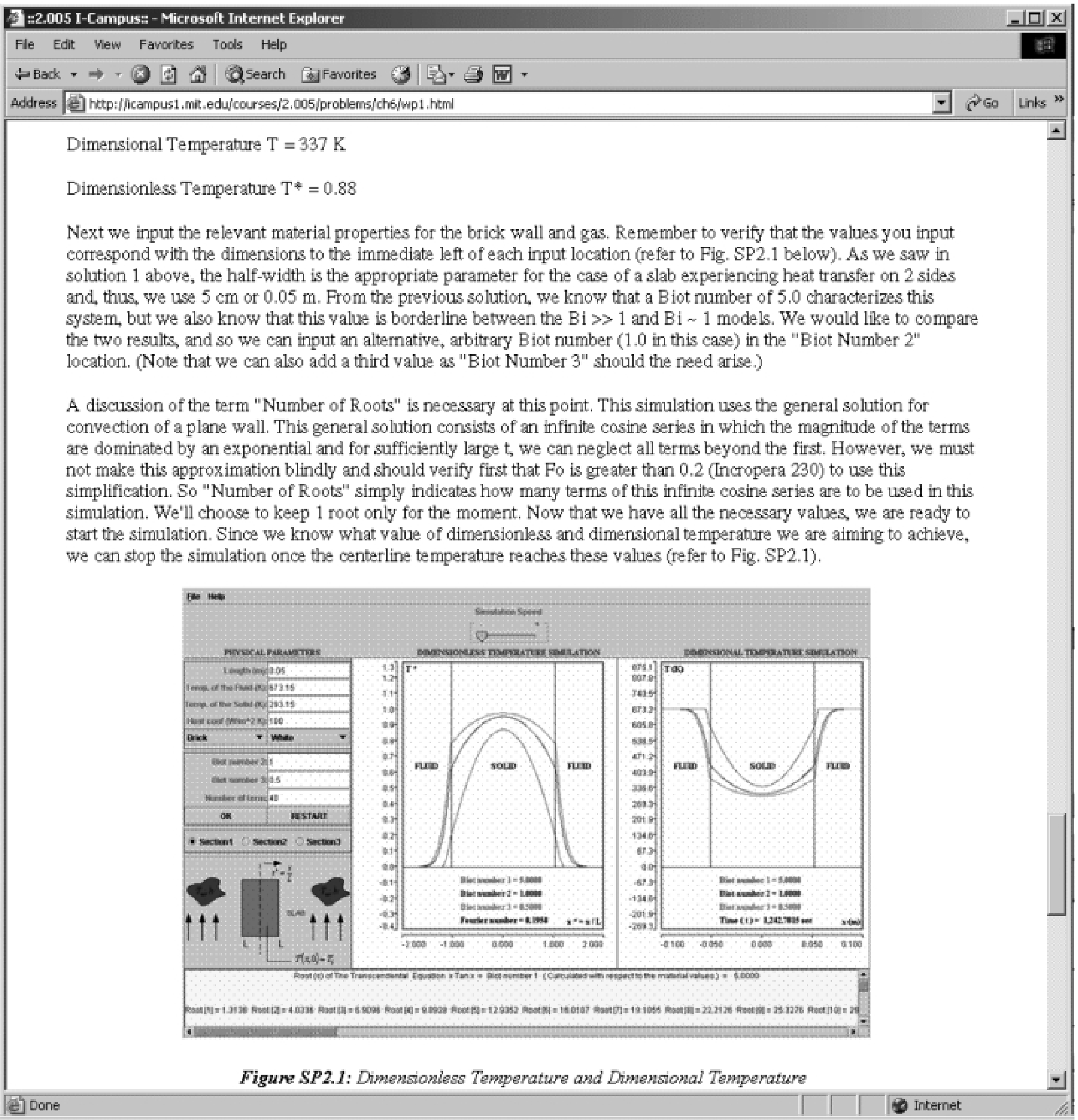

Fig. 8. Discussion of a mathematical feature of the simulation important to an understanding of the solution produced using the simulation.

mathematics and accuracy of his or her solution that they carry a number out to four decimal places or more when there is no basis for claiming that degree of accuracy. Solving open-ended problems can help highlight the difficulty of choosing an appropriate model and what sorts of approximations and assumptions to make.

The difference between the worked problems and real world examples lies in the goals of the problem. In the former, it primarily is to gain confidence and familiarity with some common types or classes of problems and to learn how to apply the theoretical equations introduced in class. The real world examples section, however, focuses on growing accustomed to making difficult modeling decisions and demonstrating how theory is applied by engineering professionals, not necessarily on the numerical answer itself. Thus, the real world examples are typically more conversational and less rigid, taking on the style of a recitation or tutorial rather than a lecture.

For example, the lead shot tower example is shown in part as Fig. 9. A rather ingenious method for cooling molten lead into spheres of a specific diameter was developed when it was recognized that dropping molten lead through a sieve from a sufficiently large height would cause the lead to solidify due to the convective cooling action of the air during free fall. In this presentation of the particular design employed in the Phoenix Shot Tower built in 1828 in Baltimore, Maryland, the design features and steps involved in calculating the required height are discussed. Hence, by presenting a practical application of the theory, the student is able to develop both proficiency in the use of important thermodynamic relations as

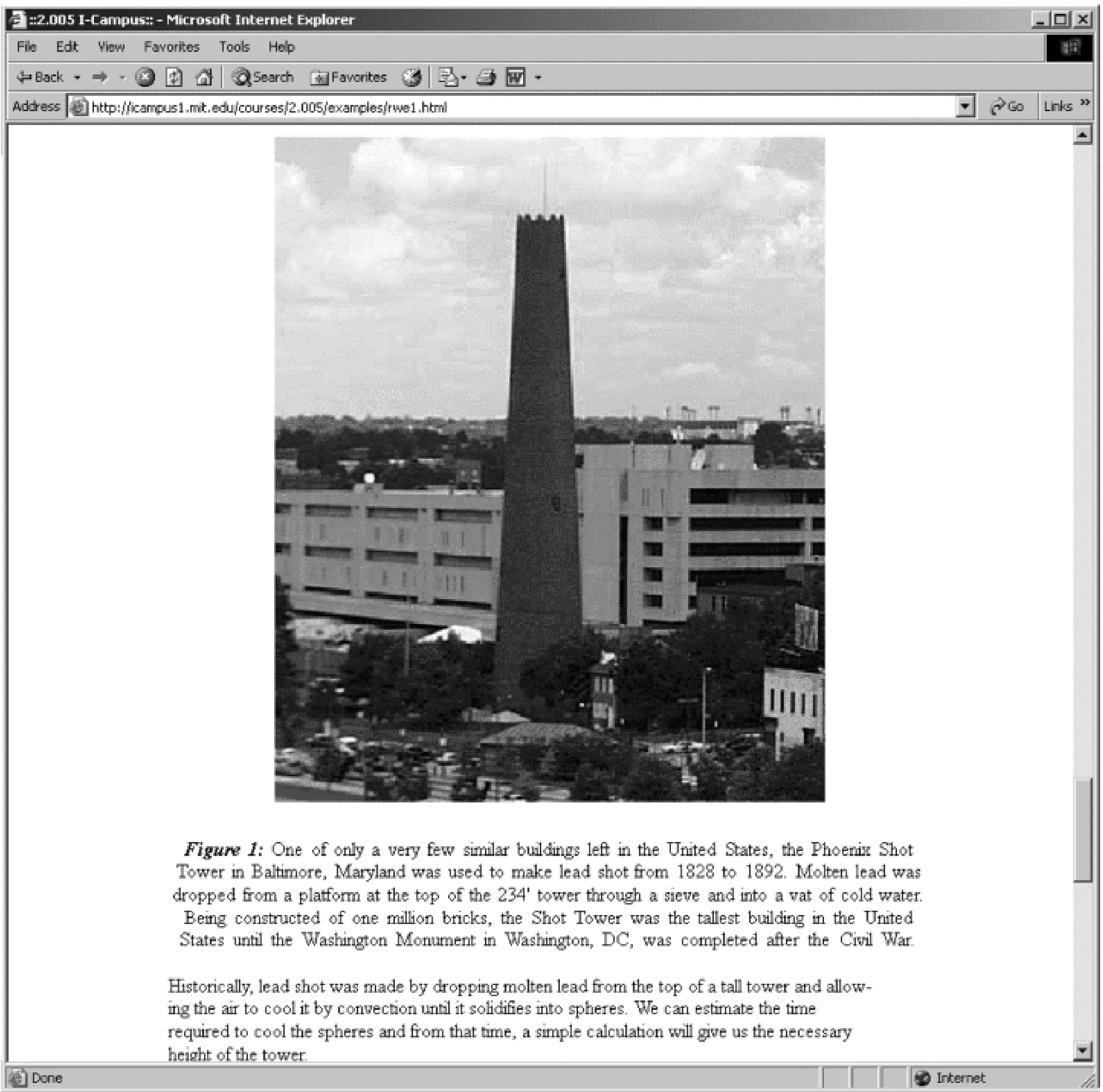

Fig. 9. Real world examples section. This image shows a brief introduction and description of the lead shot tower example as it appears on the I-Campus website.

well as competency and intuition in the application of simplifying assumptions and models.

REFERENCE SECTION

This section includes some tables, calculators, and formulas related to heat transfer interactions in thermal-fluids systems and are arranged identically to the information section. Generally this part can be thought of as an appendix of the topic as the student can find supplementary materials related to the module topics in this section. Examples of topics covered include the general form of the solution of the dimensionless temperature distribution for slabs, cylinders and spheres, coefficients in the one-term approximation for convection cooling of slabs, cylinders, and spheres, the first six roots values of the transcendental equations for slabs, cylinders, and spheres, complementary error function values, Bessel functions values. In addition, this part contains four calculators such as a transcendental equation solver, complementary error function calculator, Bessel function calculator, and convective cooling constants calculator. This part also includes one chart simulation called the Centerline Temperature Simulation which allows the user to obtain the dimensionless temperature values versus Fourier number.

FUTURE WORK AND RECOMMENDATIONS

This research is part of the I-Campus project and is still under development for several topics covered in *2.005 Thermal-Fluids Engineering I* and

2.006 Thermal-Fluids Engineering II. As a next step, the heat transfer interactions in thermal-fluid systems module will be introduced in the classroom in lecture and recitation hours as supplementary lecture materials for the coming school term. No formal assessment of these tools has been made; although, initial faculty reaction to these tools has been positive. The impact of these web-based tools will be more formally assessed at the end of the year's use in the classroom.

Additionally, new technologies are being examined for their applicability to Web-based education. Currently, the most promising of these are the use of fluid mechanics experimental movies and lecture movie series, online lectures, and Macromedia's Flash. Development of animations or short online 'recitations' illustrating and illuminating classical problems that might defy simulation methods such as those described above is in progress.

Acknowledgements—This research has been funded by the Microsoft sponsored MIT I-Campus initiative and MIT School of Engineering.

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