2006-467: INTERACTIVE COMPUTER PROGRAM FOR ENHANCING CONDUCTIVE HEAT TRANSFER CONCEPTS

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Interactive Computer Program for Enhancing Conductive Heat Transfer Concepts

Abstract

A computer based interactive learning tool for students enrolled in the Heat and Mass Transfer course for undergraduate students was developed. The program is based on a code developed through a private contract with Sandia National Laboratory for steady state and transient heat conduction in solids. The interface, which was developed as part of this research, between the student and the kernel program, allows visualization of steady state conductive heat transfer in one and two dimensions. The program is used by students on an individual basis as a supplement to their usual textbook, homework and class involvement. Input from the students is prompted via text boxes in a Windows based program. A rectangular shaped solid object is presented in the program window when the program is first launched. Each of the four sides of the object is afforded an input box for the student to type the prescribed temperature for each of the edges of the body. Overall height and width input boxes must also be filled in by the students. Once the "start" button is depressed, the temperature calculations are automatically performed and the temperature distribution is displayed. Students enrolled in the Heat and Mass Transfer course are given instruction sheets for operating the program, including prescribed temperature values for the boundaries. They are then asked to provide a written response to questions, requiring them to explain where the heat flux is the largest and the smallest in the body. An evaluation of the program by the students is included in the study as a means of determining the effectiveness of the program.

Introduction

Giving students an intuitive physical feel for steady state thermal conduction is an important part of any heat transfer curriculum. Imparting this depth of understanding to students can be difficult in a typical classroom setting. Indeed, even with the aid of textbooks and printed images, there is a significant barrier to overcome in imparting this intuitive feel. Allowing the students as much hands-on experience as possible with the principles of steady state thermal conduction seems to hold the most promise for instilling these concepts at the intuitive level. As such, the subject program of this paper was developed to be used as a supplement to existing classroom lecture and textbook use.

The program is based on a code developed through a private contract with Sandia National Laboratory for steady state and transient heat conduction in solids. This program, called "verif.exe" is DOS based, and as such, is not as easy to use as programs which run in a Windows environment. The DOS program "verif.exe" uses a very efficient calculation method called "time partitioning" [1] which allows temperature solutions to be computed very quickly. This method involves the sum of two solutions for computing temperature. A "long time" solution involving eigenvalues and series terms is added to a "short time" solution, which arises from the Laplace transform or semi-infinite approximation. This method usually allows convergence of the series solution with only a few terms, giving accuracies of 8 significant digits or more. Typical solutions of steady state conduction of infinite series form require thousands of terms to achieve this level of accuracy. Although the solution sought after for the instructional computer program is steady state, convergence can actually be obtained more quickly using the time partitioning method, which solves a transient problem, evaluating the temperature at a large dimensionless time. For the steady-state problems dealt with as part of the instructional program, the equation that is solved is the two dimensional Cartesian form of the Laplace equation, which is

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} = 0 \qquad (1)$$

The boundary conditions for this equation are all prescribed temperature boundary conditions, with temperature values selected by the user.

The limitation associated with "verif.exe", the kernel DOS program for this work, as an instructional tool, is that the interface between the user and the program is somewhat cumbersome. An input file must be used which is designed to be compact and can therefore seem cryptic in nature, making it difficult to use, until the user acquires some familiarity with the program. Moreover, most students in the customary undergraduate age bracket have had very little or no exposure to DOS-based programs and are unfamiliar with the standard commands which are used in starting programs, changing directories, etc. Therefore, this DOS based tool, while very powerful and accurate, is not well suited for instructional purposes for undergraduate students. The interface program between the student and "verif.exe", which was the component developed as part of this research, allows visualization of steady state conductive heat transfer in two dimensions. This program is intended to serve as a bridge between the student and "verif.exe" to facilitate expanded instructional features. It therefore supposes to provide both the interactive feature unavailable in textbooks, and the user-friendly feature unavailable with a tool such as "verif.exe".

Program Features

The program addresses steady-state heat conduction in a rectangular two-dimensional object. The intended implementation of this program is as a homework exercise during the thermal conduction segment of an undergraduate heat transfer course. Handing out a physical storage device of any kind is unnecessary because the program can be placed on a web drive and run by students over the school's network, as long as the drive is accessible to all of the students. The students are assigned a list of tasks they are to perform as part of their assignment in running the program. They are asked to perform several pre-selected functions using the program, as well as one problem of their own choosing. For each problem, they are asked to answer several questions related to temperature and heat flux. The interactive nature of the program allows the students the opportunity to experiment with some of the parameters that affect the final temperature distribution. This, in turn, allows the students to feel more ownership for their homework, since they have a say in determining what some of the questions should be.

The main program is Windows based and is in a stand-alone executable format, so no additional overhead programs or specialized mathematical software are required. Students can run the program on their own personal computers or any other Windows based machine, provided that permission is available to access the network drive on which the program resides. If a particular school does not have the capability to provide a network drive accessible to all students, the program can be placed on the internet and downloaded by students to be run on their individual computers.

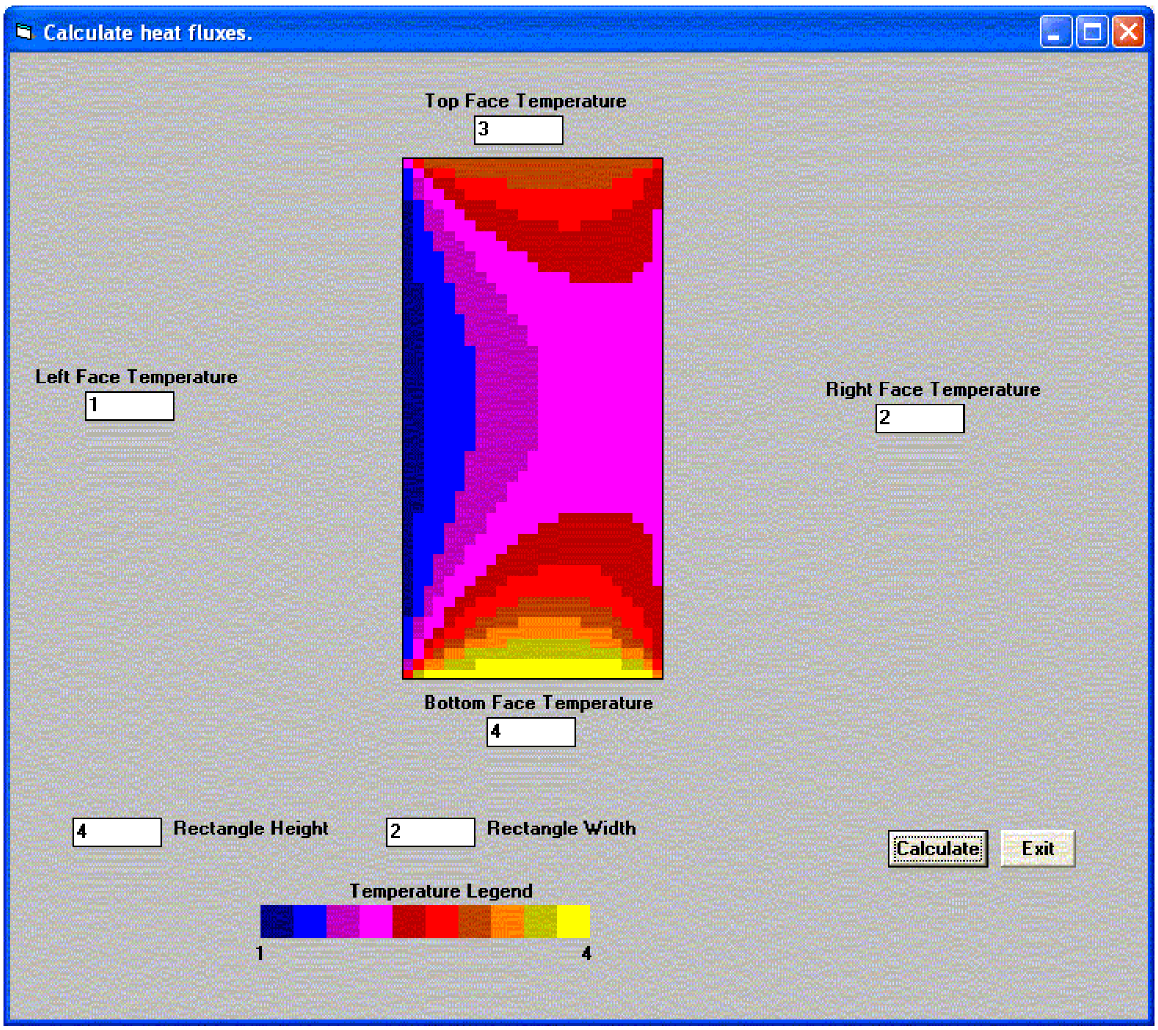

Figure 1: Sample screen from program.

A blank rectangular shaped solid object is presented in the program window when the application is first launched. There are six required items to be input by the user. Each of the four sides of the object is afforded an input box for the students to type the prescribed temperature for each of the edges of the body. The other two input items are the overall object height and width, which must be typed into text boxes by the students. The dimensional information is used for scaling of the image on the screen. When the program window initially appears, the rectangle representing the object to be heated is shown as a square on the screen by default, since no dimensional information has been input. The overall dimensions of the square are 5000 x 5000 pixels, which typically corresponds to approximately 4 x 4 inches on the screen, depending on screen size and resolution. The user then provides the six input items (temperatures and dimensions) by typing them into the appropriate boxes, as labeled on the screen. The user next hits the "Calculate" button, which activates program "verif.exe" by automatically introducing a DOS window onto the screen and the temperatures are calculated. The DOS window remains on the screen until the calculations are complete and the output of verif.exe is automatically printed to a text file, which is unseen by the user. The text file is then automatically read by the main Windows program and this information is used for generating the color plot representing the temperature distribution. See Figure 1 for an example of an object with nominal overall dimensions of 4 x 2.

The rectangular plot is scaled such that the longer of the two dimensions is 5000 pixels, and the other dimension is shortened proportionally. For example, if the user specifies a rectangle with a width of 4 and a height of 2, the program will scale the rectangle to have a width of 5000 pixels and a height of 2500 pixels. There are 10 colors used for depicting temperature, ranging from a bright yellow for the hottest temperature to a dark blue for the coldest. A legend is provided at the bottom of the window shows the user which temperatures correspond to which colors. The squares are of a dimension of 100 pixels, so there are 50 squares along the largest dimension of the rectangle. The number of squares in the shorter dimension of the rectangle is scaled in proportion to its length with respect to the longest side. Therefore, the maximum number of squares used by the program is 50 x 50, or 2500, in the case of an overall square object. Correspondingly, there is a maximum of 2500 temperature calculations that have to be performed by "verif.exe", so the case of a square object requires the most time to calculate. An object with a narrower aspect ratio would require fewer squares in the graphical window and correspondingly fewer calculations to be performed, allowing the display to generate more quickly. The time required for the display to generate in most cases is less than 10 seconds on a 2 GHz CPU.

It should be noted that no units are required in terms of the overall dimensions on the object for which the temperature distribution is displayed. Since the boundary conditions are specified in terms of prescribed temperature, the temperature distribution inside the object will be the same for any object of proportional dimensions. In other words, if the overall dimensions are specified as 4 x 2, the temperature distribution will be the same as for an object of dimensions 2 x 1 or 8 x 4, or for any dimensions where the height is twice the width. Likewise, neither thermal conductivity, material density, or specific heat are required input arguments. Since the problem is not transient, and no heat transfer coefficient or heat flux is given at any boundary, the temperature distribution in the rectangle will be the same for any material properties.

There is presently no formal provision for saving the program output; perhaps this could be a feature added in a subsequent revision. With the program in its present form, if the user desires to capture an image generated by the program for a particular case, this can be done by depressing the "alt" and "print screen" buttons, followed by pasting the captured image into a graphics program. The image can then be saved in "jpg" or "gif" format.

Results

The program was run by students in two sections of the undergraduate heat and mass transfer course, during the spring semester of 2006. The program was run in the form of a homework assignment. The students were given a list of questions to answer, related to several steady state conduction problems. They were also instructed to download the program from the teaching drive on the network, to which they all had access rights. The questions asked of the students were as follows:

1.) Display the temperature distribution for an object of width 2 and height 4. Make the left face 100^o, the right face 200^o, the top face 300^o and the bottom face 400^o. Consider the origin of the coordinate system be at the lower left hand corner of the object.
    a.) Determine the highest temperature on the object.
    b.) Give the approximate coordinates for the location of this point.
    c.) Determine the lowest temperature on the body.
    d.) Give the approximate coordinates for the location of this point.
    e.) Give the approximate coordinates for the location of the highest heat flux on the object.
    f.) Give an approximate direction for the flow of heat at this point, using the conventional radial coordinate system with zero degrees along the *x* axis and increasing angle in the counterclockwise direction.
    g.) If the thermal conductivity of the material had a value of 1 at this point, what would you estimate the magnitude of the heat flux to be?
    h.) Give the approximate coordinates for the location of the lowest heat flux in the object.
    i.) Give an approximate direction for the flow of heat at this point, using the same radial coordinate system.
    j.) If the thermal conductivity of the material had a value of 1 at this point, what would you estimate the magnitude of the heat flux to be?

2.) Now run the program with the same temperature boundary conditions, but with the height and width reversed. In other words, let the height be 2 and the width be 4. Now answer questions (a)-(j) above, as well as the following:
    k.) Is the overall material in this case hotter, cooler, or approximately the same as in problem 1? Give an explanation for your answer.
    l.) Is there a location on the body where the heat flux could possibly be zero? If so, give the approximate coordinates of this location.

3.) Now run a case of your own choosing and print out the results or sketch what you see on the screen. What observations can you make about differences in the program results between your chosen case and the two cases above in terms of calculated temperatures and apparent heat fluxes? What is the reason for these differences?

The only technical difficulty encountered in deploying the program was that a security restriction prohibited the students from running the program directly in place on the faculty web drive. Although the students have reading access to this drive, they do not have write access. Since the

DOS program and the graphical interface communicate with each other through a file, which resides in the same directory as the program, the lack of write access on the part of the students prohibited them from fully executing the program. The solution to this was simply to have the students copy the program from the faculty drive to the students' own directories and run the program there.

The course instructor felt that the project, supported by lectures in two-dimensional heat transfer, enabled the students to better visualize the two-dimensional temperature distribution. This opinion was supported by classroom discussions and project grades. The students had clearly developed a deeper understanding of temperature gradients and the resulting conductive heat transfer in a two-dimensional solid. In order to determine how the students viewed the value of this project they were surveyed. Thirty one of the 32 students taking the class completed the survey. The survey, with the tabulated results, is as follows:

Question 1.
The problem enhanced my understanding of steady conduction heat transfer (heat flux) in a two-dimensional solid

Strongly Disagree	*Disagree*	*neutral*	*Agree*	*Strongly Agree*
0	0	8	15	8

Question 2.
The problem enhanced my understanding of temperature distributions due to imposed boundary conditions.

Strongly Disagree	*Disagree*	*neutral*	*Agree*	*Strongly Agree*
0	1	4	11	15

Question 3.
The problem enhanced my appreciation of the use of the computer in the solution of heat transfer problems.

Strongly Disagree	*Disagree*	*neutral*	*Agree*	*Strongly Agree*
0	2	7	10	12

Question 4.
I found the project enhanced my understanding of the course material.

Strongly Disagree	*Disagree*	*neutral*	*Agree*	*Strongly Agree*
0	2	9	17	3

Question 5.
The project was relevant to our study of conduction heat transfer.

Strongly Disagree	*Disagree*	*neutral*	*Agree*	*Strongly Agree*
0	0	3	15	13

The student survey reflects a highly favorable reaction from the students. There seems to be consensus that the approach of using a graphic output to a two dimensional temperature distribution has enhanced student understanding of conduction heat transfer. The survey also indicated that the project enhanced the students' appreciation of the use of the computer in the solution of heat transfer problems. This initiative demonstrated that the computer can be a powerful tool which can be used to make the solution of complex problems more convenient and appropriate for classroom assignments.

Future Plans

The intentions for the future use of this program are to continue to develop new features, such as the addition of other boundary conditions, including convective boundary conditions and specified heat flux boundary conditions. Other intended improvements include speeding up the calculation time of the program and making the graphical display smoother. Although these goals are mutually opposing in some ways, the calculation grid should be expandable by changing the method used in the display feature of the program. Currently, squares are used as the fundamental geometric shape of the display, which tends to present a very jagged appearance in all but the most ideal cases. Instead, displaying the colors using trapezoidal or other polygonal shapes would allow the borders between colors to follow isotherms much more closely, presenting an improved smoother appearance of the temperature grid. The improved smoothness rendered by this method should allow a coarser temperature grid, reducing the number of points at which temperature is required to be calculated, thereby reducing the calculation time.

At some point in the future, it is intended to develop the capability for the program to handle transient conduction cases so that the students can watch temperature distributions change in real-time. This will undoubtedly require a separate "calculation time" for the computer to obtain the numerical solutions and the graphic display phase will be a separate event. These modifications are planned over the course of the next year.

References

[1] R. McMasters, K. Dowding, J. Beck, and D. Yen, "Methodology to Generate Accurate Solutions for Verification in Transient Three-Dimensional Heat Conduction," *Journal of Numerical Heat Transfer*, Part B, Vol. 41, pp.521-541, 2002.