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NASTRAN'S APPLICATION IN AGRICULTURAL ENGINEERING TEACHING AND RESEARCH

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SUMMARY

Finite element analysis has been recognized as a valuable solution method by agricultural engineers. NASTRAN has been obtained by the Agricultural Engineering Department at the University of Georgia. The NASTRAN Thermal Analyzer has been used in the teaching program for an undergraduate course in heat transfer and will be used for a new graduate course in finite element analysis. The NASTRAN Thermal Analyzer has also been applied to several research problems in the Agricultural Engineering Department.

INTRODUCTION

Twenty years ago as engineers and computer scientists were initiating work on NASTRAN, I am certain that they never thought that their finite element analysis program would be applied to the solution of engineering problems in agriculture. In fact, many people are likely unaware of the existence of agricultural engineering. The most popular misconception of an agricultural engineer is that of a grease-covered farmhand tinkering with a sputtering tractor. While agricultural engineers deal with the design, production, and testing of farm machinery, they are involved with a wide range of engineering problems. Agricultural engineers also work in the areas of farm structures and their environments; soil, water, and plant relationships; food production and processing; the application of microelectronics to agriculture; and the management of agricultural wastes. Agricultural engineers face a wide realm of problems and must utilize the latest technology and techniques to solve them. It is little wonder that agricultural engineers have become involved with the finite element method as a solution method for problems in all the previously mentioned areas.

The use of finite element analysis by agricultural engineers began in 1974. An instructional workshop on the use of the finite element method was presented at the 1974 Winter Meeting of the American Society of Agricultural Engineers. The workshop was organized by Drs. Larry Segerland and Robert Gustafson. Segerlind and Gustafson have each published numerous research papers which apply the finite element method to agricultural problems; organized courses at Michigan State University and the University of Minnesota, respectively; and have written software to encourage the use of finite elements. Segerlind has written an excellent text for a first course in finite element analysis entitled, Applied Finite Element Analysis (1). Several research papers have been published since 1974 by agricultural engineers utilizing the finite element method for such problems as determining the shrinkage stresses of soybeans during drying (2); modeling stomatal guard cells in plant leaves (3); measuring the mechanical and thermal strength of avian eggs (4); the freezing rates of food products (5); and the thermal analysis of livestock housing (6).

Agricultural engineers, like engineers of other disciplines, have employed the finite element package programs such as NASTRAN, STRUDL, and ANSYS. NASTRAN was obtained by the Agricultural Engineering Department at the University of Georgia in July, 1983. It has since been incorporated into an undergraduate course in heat transfer, and will soon become part of a graduate course in finite element analysis. The NASTRAN Thermal Analyzer (NTA) has been useful for analysis in several projects in areas such as structural environments, post-harvest handling of vegetables, and biomass fuels. The purpose of this paper is to describe the application of NASTRAN to the teaching and research program of the Agricultural Engineering Department at the University of Georgia.

INSTRUCTIONAL APPLICATION

A basic course in heat transfer is required of all students majoring in Agricultural Engineering at Georgia. This course, taught during the junior year, is designed to introduce the students to conduction, convection, and radiation heat transfer. Approximately 25 percent of the course is devoted to an introduction to numerical methods for solution of heat transfer problems. The finite difference method is introduced initially, followed by an introduction to finite element analysis. Usually three, simple, one dimensional transient conduction problems are assigned for solution using finite differences on a microcomputer. These same problems are later solved using NASTRAN to illustrate the benefits of a packaged program. The students are also exposed to several example NASTRAN programs during their laboratory period to show how easy it is to use finite element analysis to solve "complicated" problems. Students are encouraged to use NASTRAN to attempt to solve larger, applied problems. To illustrate the effectiveness of the finite element analysis, actual data from a simple class demonstration is compared to data generated by a NASTRAN model. The demonstration usually consists of monitoring the transient cooling of a piece of fruit instrumented with thermocouples. Using NASTRAN has allowed students to be exposed to finite element analysis without discouraging them by lengthy discussions of its theory and computing methods. The students gain an instant appreciation for numerical methods as a solution technique.

A graduate course in finite element analysis has recently been approved by the faculty of the University of Georgia College of Agriculture. The course will likely be taught during the Summer Quarter, 1985. Since the Agricultural Engineering Department is the only engineering discipline offered at the University of Georgia, the expected enrollment is five to ten students per quarter. The course is designed with the assumption that this is a first course in numerical methods for the student and that their background will consist of only a brief introduction to finite element analysis at the undergraduate level. The course will consist of the basic concepts of the finite element method including the various elements and domain discretization, the methods of equation formulation, solution procedures, computer implementation, and a sampling of software packages. Before utilizing software packages, students will be required to develop their own computer solution for a number of small problems using a microcomputer. The small class size will offer the opportunity for students to develop individual term projects. These projects will require a student to choose a particular problem, hopefully related to their thesis area, to which a finite element analysis may be applied. The numerical results will be compared to experimental and analytical data taken by the student. NASTRAN will be used as an example of a software package available on the mainframe computer, and should be an important tool which students use for the term project. Anticipated projects will involve thermal modeling of animal housing and greenhouses, fruit and vegetable processing, irrotational flow of groundwater, and the structural integrity of agricultural structures and machinery. A similar course taught since 1979 at Auburn University (7) resulted in the following interesting array of student projects: the structural analysis of a bow string truss for a center pivot irrigation system; vibration analysis of a rotary mower cutter blade; steady state water seepage in pourous media; and an evaluation of the strain distribution in a proposed load transducer for use in a tillage implement force system measurement. As was the case with its use in the undergraduate course, NASTRAN will allow the graduate students to use finite element analysis for solution of more rigorous problems without drowning with involved computer programming and development.

RESEARCH APPLICATIONS

The NASTRAN Thermal Analyzer (NTA) has been applied to several problems under study in the Agricultural Engineering Department at the University of Georgia. A short discussion of each project will be given to illustrate the application of the NTA to agricultural research.

Passive Solar Wall for Poultry Brooding

The poultry industry is very important to the agricultural economy of Georgia. Broiler chickens, which are slaughtered at seven weeks of age, accounted for over $610 million in sales at the farm level in Georgia during 1982. Birds less than 2 weeks old require supplemental heat, usually provided by LP gas burners, to maintain their body temperature. Although Georgia has a relatively mild winter climate, the primary factor in poultry house design is the summer heat. Only recently have enclosed, insulated, fan ventilated poultry houses been built in Georgia. A tremendous amount of brooding heat is necessary during the winter months regardless of the type of house construction because of ventilation air flow necessary to limit heat and moisture, and because of brooding temperatures between 29 and 35 C.

One method to reduce the heat consumption is to use partial house brooding where birds are contained in only a portion of the house to reduce the air volume heated. The use of solar heat has also been studied, primarily using active systems. Instead of an active system, the Agricultural Engineering Department explored the feasibility of using a south facing, passive solar wall. The wall could be constructed of poured concrete and tilted into place as a retrofit on existing houses with a southern exposure, or easily included in new construction. A project was initiated to investigate the feasibility of a concrete passive solar wall in a Georgia broiler house using partial house brooding. The design process could be most efficiently handled by a thermal model using the NTA for finite element analysis. This project consisted of (a) a wall thickness and conductivity test, (b) a verification of the finite element application, and (c) the simulation of the entire broiler house. The wall thickness and thermal conductivity were examined by using a model consisting of one dimensional elements (Fig. 1). The outside wall surface was exposed to the same set of boundary conditions as the wall thickness and conductivity were varied. The thermal lag time for the inside surface to reach a given temperature was the criteria used to select wall characteristics for the larger simulation. Concrete wall thicknesses of 0.1, 0.2, and 0.25 m having a thermal conductivity of 0.42 W/mC were found to deliver the majority of the solar heat to the brooding area beginning at 8 p.m., and were chosen for use in the simulation of the entire house.

This application of the finite element method was verified by comparing data from a vacant, instrumented warehouse to the simulated results. The actual and simulated data were quite close (Figure 2).

The broiler house simulated was 11 x 91.5 m, containing 13,000 chickens. Heat and moisture production data for birds at ages 1, 2.5, and 4 weeks of age were used (8). Temperature and solar data were chosen for a clear, December 21 day at Athens, GA. The passive solar wall occupied the south wall in the partial house brooding area. Half and one-third house brooding were simulated. Radiation and convective boundary conditions were used in the finite element model consisting of one dimensional elements (Figs. 3 and 4).

Results of the simulation indicated that the wall produced 1321 kW-hr of heat for a clear, December 21 day using half house brooding. The benefit of the solar wall was determined by comparison to the temperature within a similar broiler house without the wall. The solar wall raised air temperatures within the house 3 C above the conventional house for broilers 1 week old. This temperature difference between house types decreased as the birds became older because it became necessary to increase the ventilation rate (Figs. 5, 6, and 7). The outer wall surface was found to re-radiate heat after dark to the outdoors. It was necessary to use an insulated curtain (R= 1.06 m^2C/W) to cover the solar wall at night. This curtain might also reflect solar radiation from the wall during warm weather. It was concluded that the passive solar wall constructed of concrete and used in this manner was unfeasible without using additional heat sources. The cost and management of an insulated curtain are an added burden.

Insulation Requirements for Buried Thermal Storage

Georgia is among the nation's leaders in biomass production, primarily wood. There has been interest by the poultry industry in providing brooding heat birds by burning biomass furnaces. While some studies involving forced air systems have not proven feasible (9), circulating heated water through heat exchangers in the brooding area has been more promising. Concrete septic tanks are inexpensive and can be used to store the heated water. To improve the thermal efficiency of a system, the storage tank can be buried and insulated. The NTA was used to model the heat loss from a 3785 liter tank during typical winter conditions at various locations. A two dimensional finite element model was used (Figure 8). The finite element model was verified by monitoring the heat loss from a 3785 liter septic tank buried 0.3 m below grade and comparing it to data generated by the simulation. The heat loss simulated by the finite element analysis exceeded the actual heat loss by 13.1 percent over a 12 hour period.

Results of this study indicated that during a 12 hour night heat storage period in January, an uninsulated 3785 liter concrete tank buried 0.3 m below grade and filled with water heated to 60 C will lose 15 percent more heat than the same tank insulated with a material having a thermal resistance of 0.87 m^2C/W (one inch of smooth skin polystyrene). Addition of an identical second layer of insulation would only reduce the heat loss from the tank an additional 2 percent. Based on reported burning efficiencies and system losses (10), addition of an insulation material with a thermal resistance of 0.87 m^2C/W will require approximately 18 percent less cord wood than a system with an uninsulated tank.

Thermal Analysis of Nursery Containers

Commercial plant nurseries commonly grow plants in black and green nursery containers. The growth media in the containers can reach temperatures of 50 C or greater as a result of solar radiation. Plant root growth retardation generally occurs above 30 C, while growth cessation occurs above 28 C. Root damage may occur at media temperatures greater than 45 C (11). Several attempts have been made to alleviate the thermal stress suffered by plant roots including using perforated containers, white plastic containers, and evaporative cooling (12). Most studies of container soil temperatures have been empirical (11). A finite element analysis using the NTA is currently in progress to quantify the thermal environment of a nursery container exposed to summer solar radiation. A three dimensional model comprised of wedge elements is being used (Figure 9). In hopes of reducing high media temperatures, the following parameters are being investigated: a) container surface color, b) media composition, c) container geometry, and d) the container dimensions.

Post-Harvest Cooling of Southern Peas

The development and use of pea harvesting combines has resulted in more efficient and economical harvesting and allowed for an increase in planted acreage (13). An indirect problem resulting from this improvement in mechanization and larger pea harvest is post-harvest quality deterioration due to excessive temperatures of the peas before they can be cooled at the processing plant. Quality loss begins when the pea temperature reaches 25-30 C. Temperatures of peas harvested during summer when the air temperature is 32 C frequently rise to approximately 45 C as the peas are loaded in bins for transport from the field. Agricultural engineers are investigating the use of convective and evaporative cooling of the post-harvest peas while enroute to the processing plant. An initial finite element model using the NTA is being used to investigate the required air velocity to produce sufficient convective cooling to maintain pea quality. A two dimensional finite element model of an individual pea is being evaluated (Figure 10). Modeling of several peas in a bin with void spaces filled with air is currently being developed.

CONCLUSION

The finite element method has been applied to a wide array of agricultural problems. NASTRAN has been very beneficial in applying the finite element analysis in research projects, and in developing a positive attitude for numerical solution methods in the students who are in the instructional program. Engineers are able to use the finite element analysis as a solution technique without becoming mired in computer programming and the theoretical background of the method. Use of NASTRAN will expand in the Agricultural Engineering Department at the University of Georgia beyond the current use of only the NTA. Student and faculty interest, already evident, will apply NASTRAN to several new applications.

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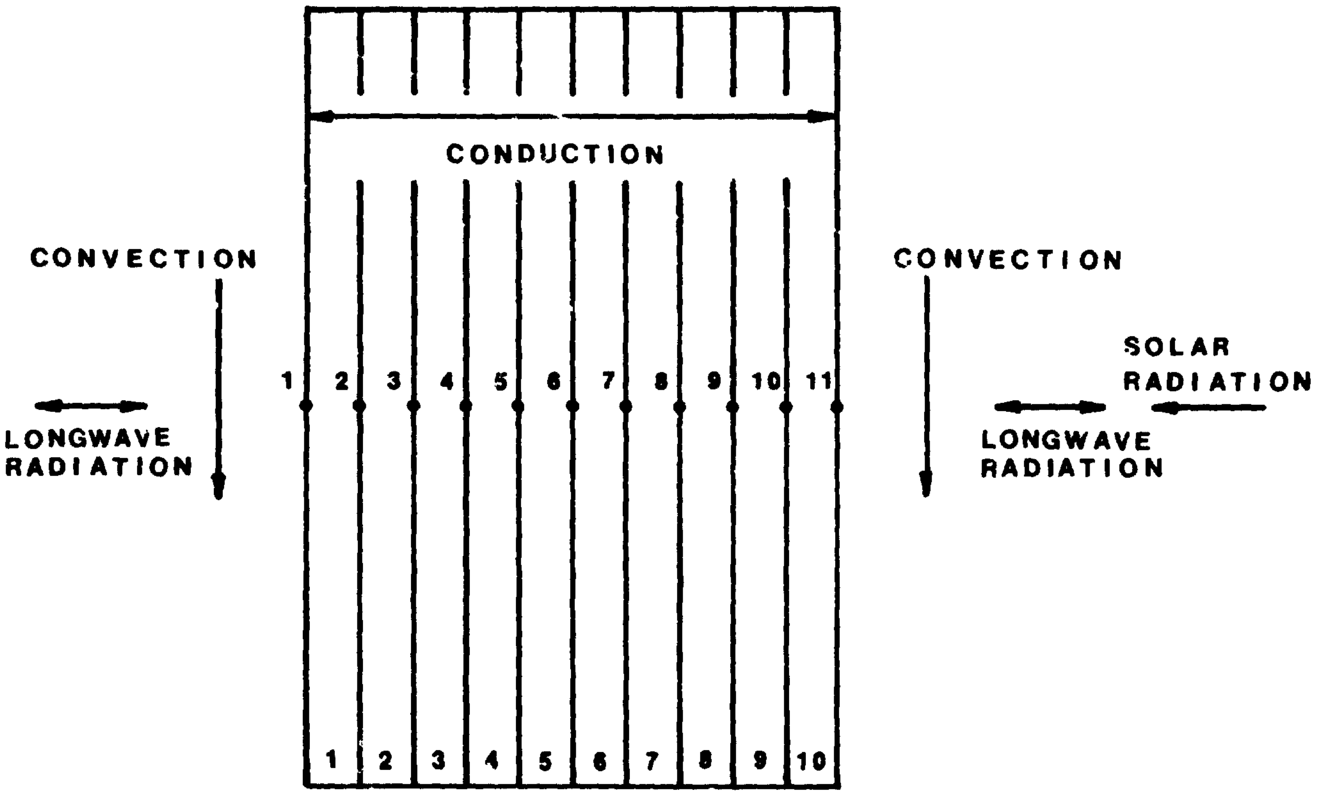

Figure 1. Finite element grid for the passive solar wall simulation.

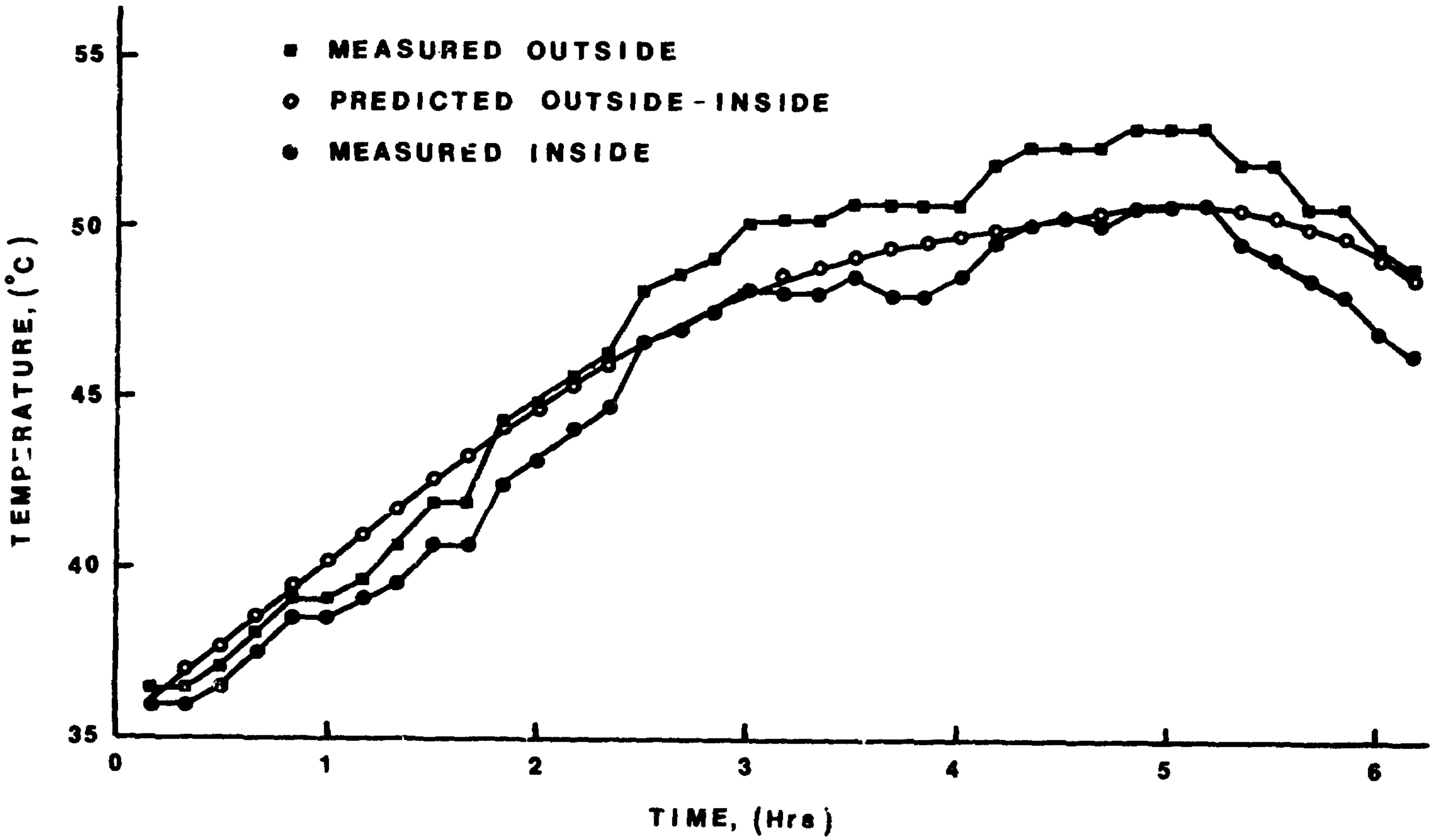

Figure 2. Wall temperature versus time of measured and predicted thermal analysis.

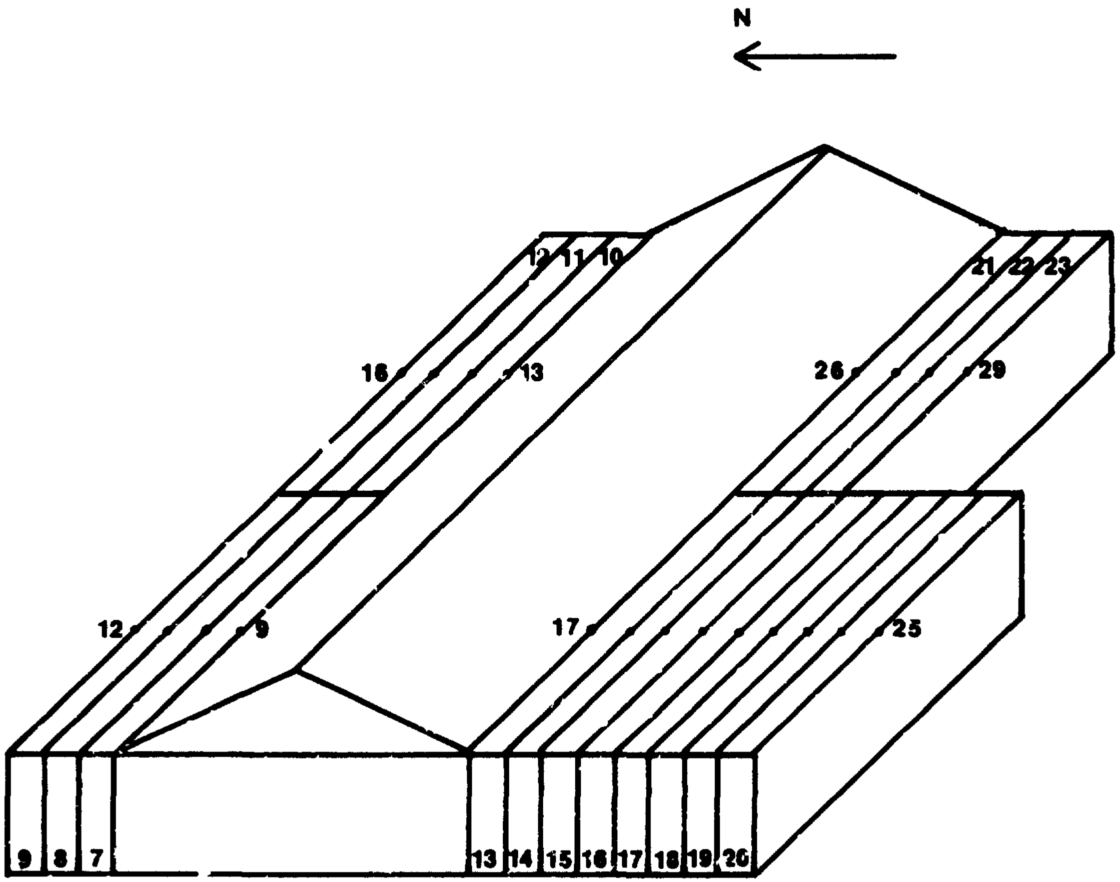

Figure 3. Finite element grid for sidewalls of the simulated poultry house using half house brooding.

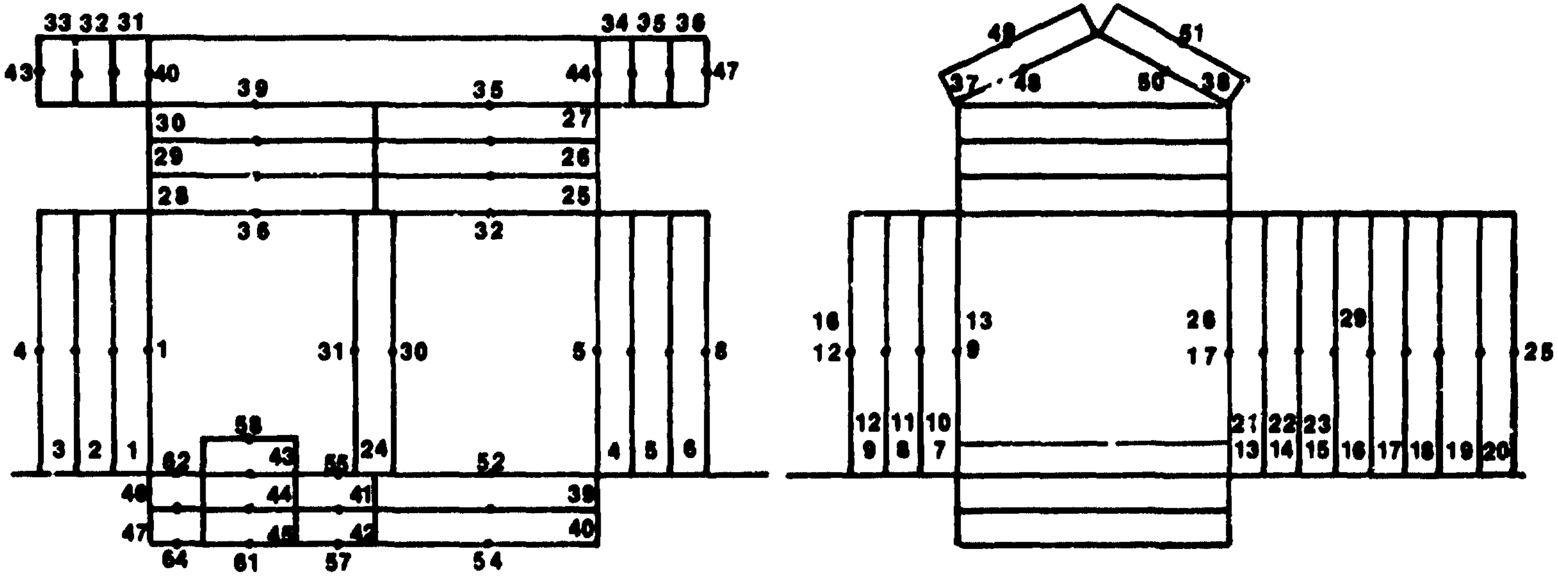

Figure 4. Finite element grid of the simulated poultry house (side and west views).

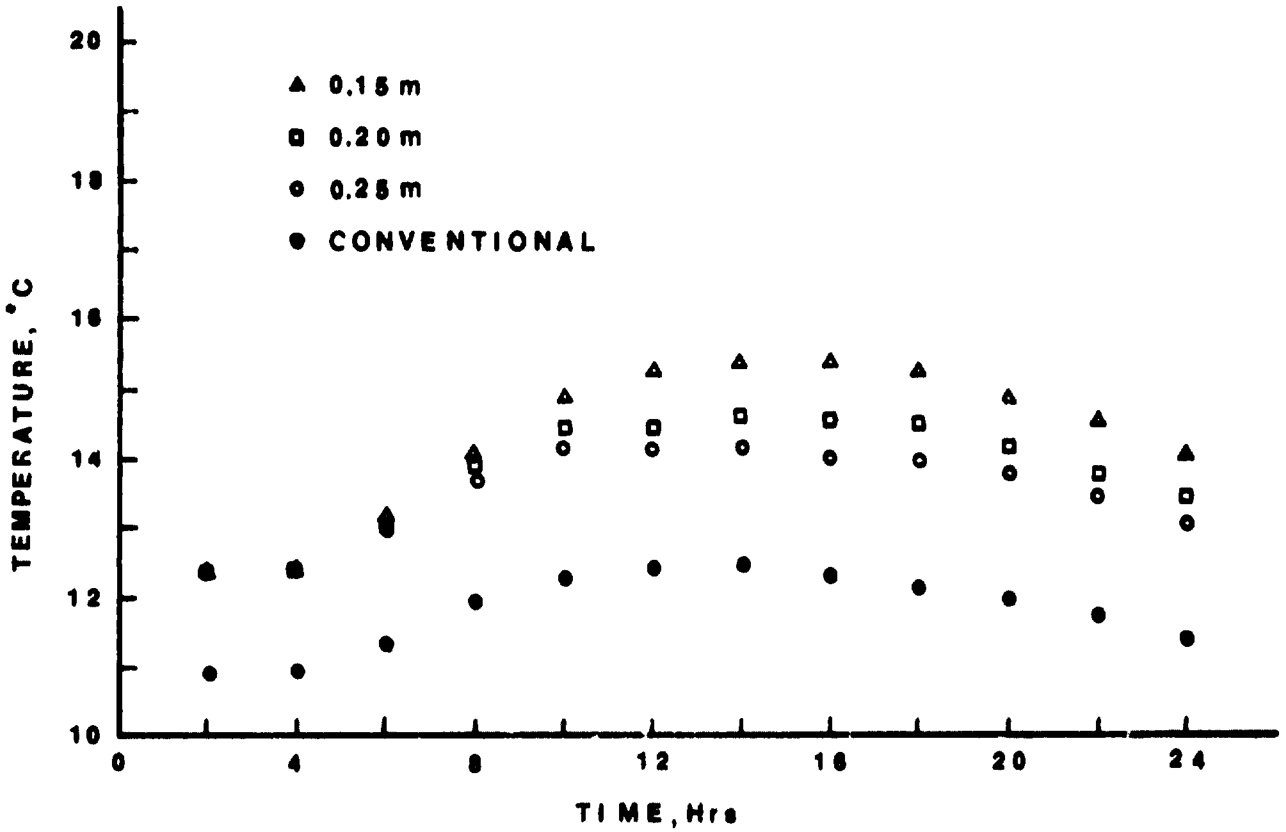

Figure 5. Brooding area temperature versus time for half house brooding for 1 week old birds.

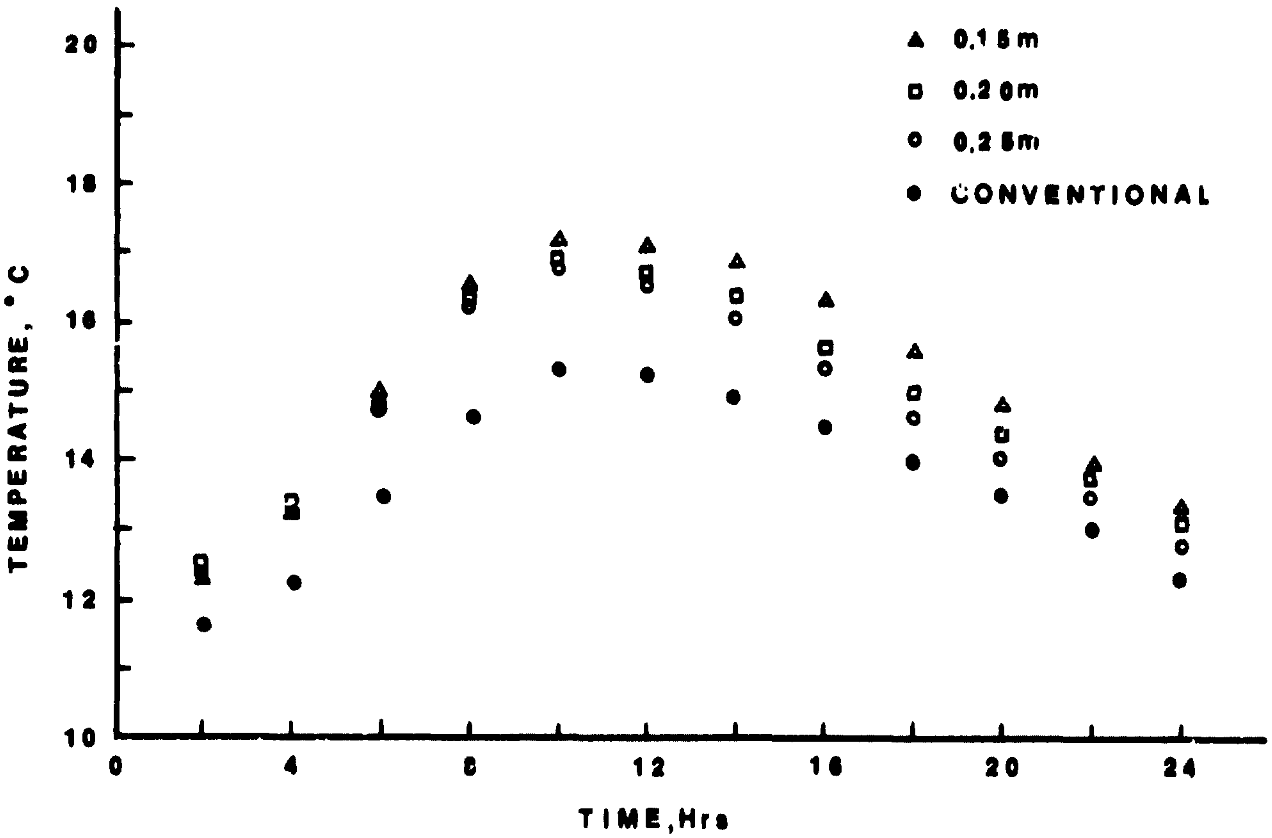

Figure 6. Brooding area temperature versus time for half house brooding for 2.5 week old birds.

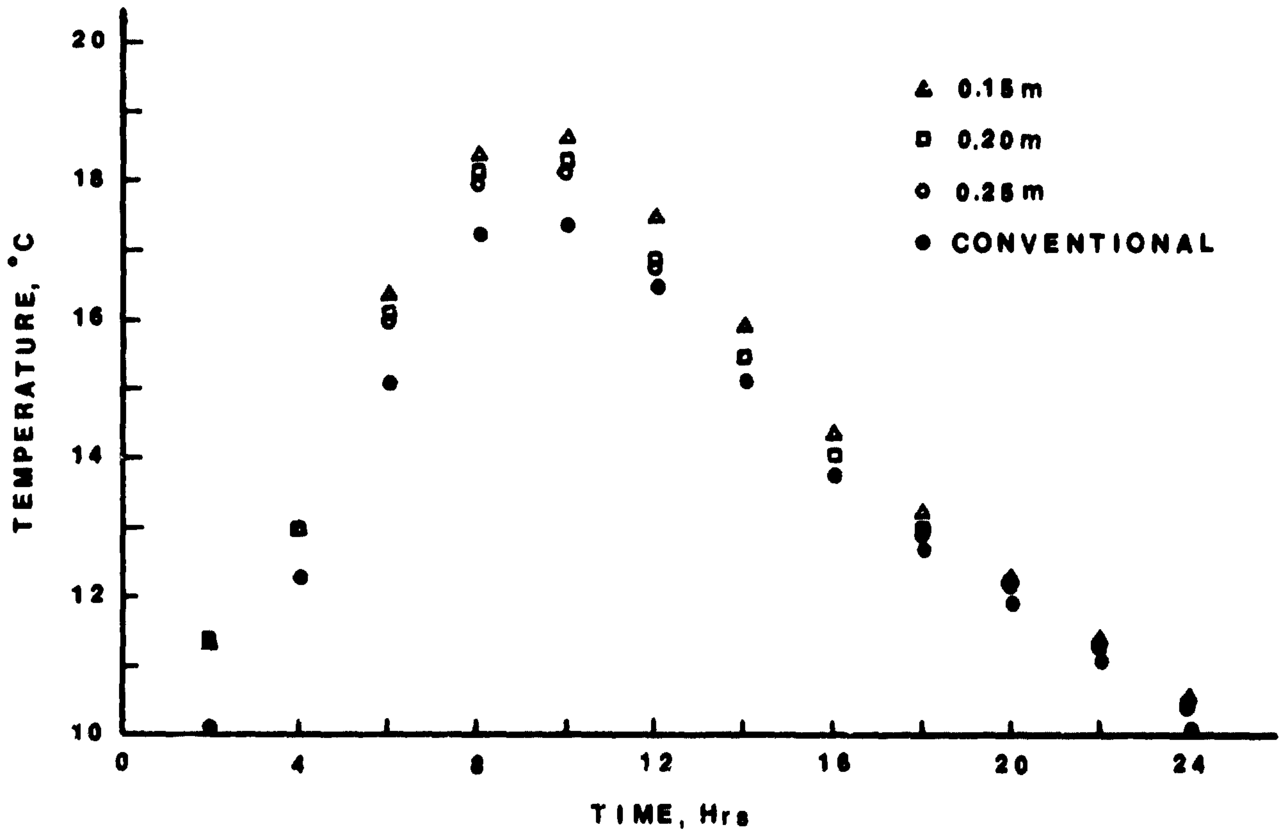

Figure 7. Brooding area temperature versus time for half house brooding for 4 week old birds.

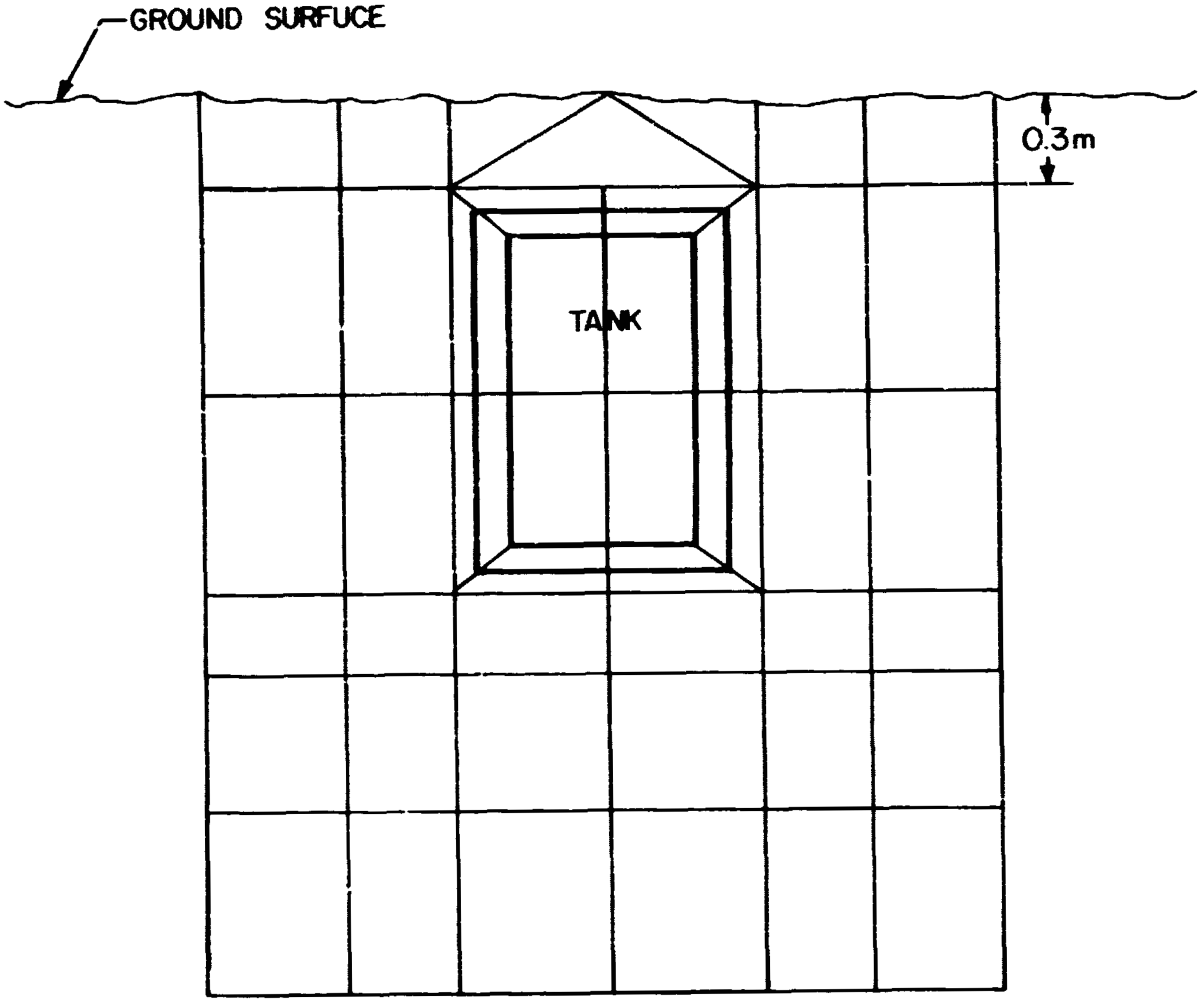

Figure 8. Finite element model of a buried thermal storage tank.

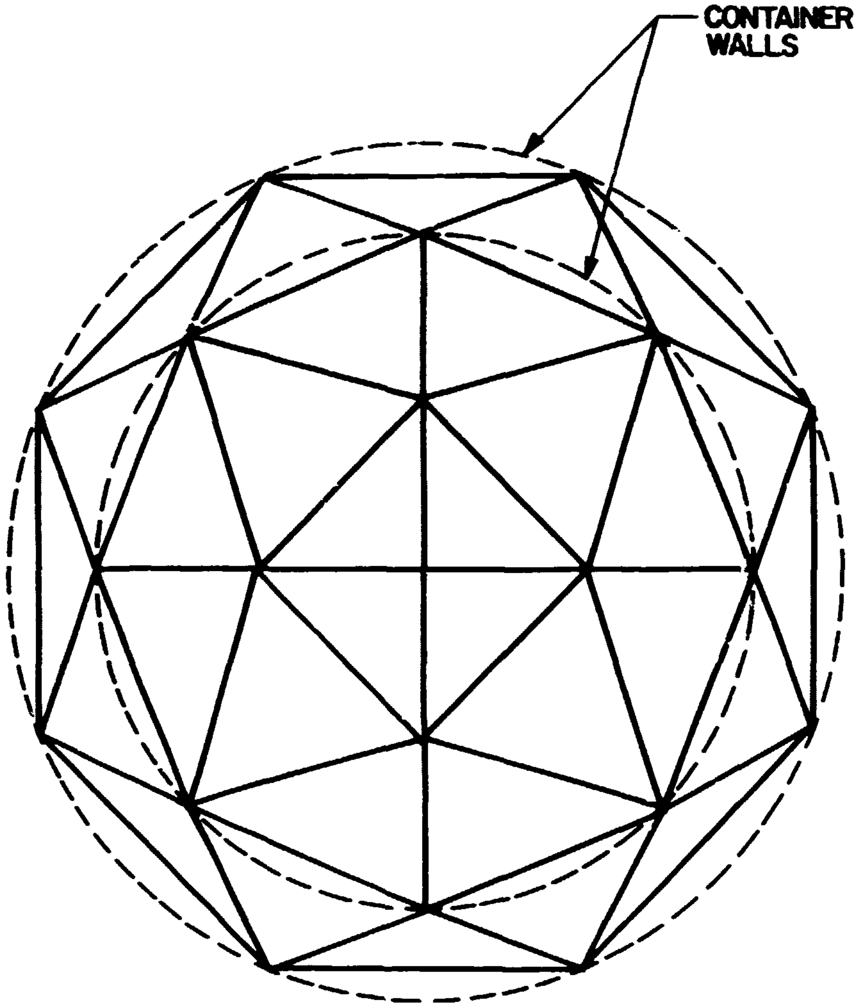

Figure 9. Finite element model of a nursery plant container.

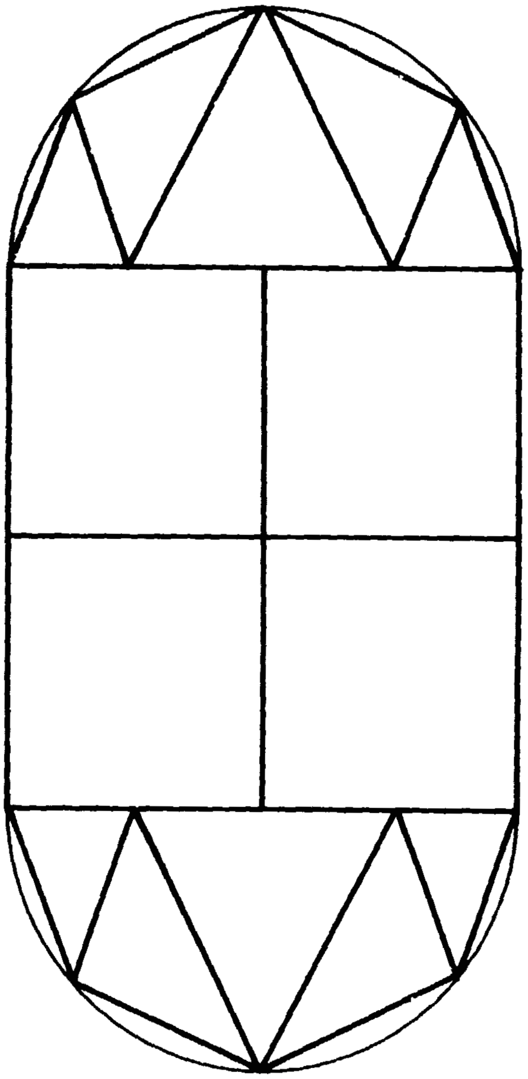

Figure 10. Finite element model of a southern pea.