LINKING SCIENCES AS A DESIGN TOOL

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ABSTRACT
Industrial design engineering students often have problems in establishing theoretical models to predict product behaviour. The problem is not to solve mathematical equations, but to translate real life behaviour into mathematical equations. Current engineering education is strongly focused on mechanics rather than electronics, despite the fact that industrial design engineering is multidisciplinary. Therefore, it has been decided to teach system dynamics as a modelling tool for engineering design problems. All mechanical, thermal, hydraulic and electric problems can be seen as an electric circuit. Several graduation students have been encouraged to use this analogy approach to system dynamics.
After a crash course in heat transfer, students were able to use analytical models to enhance their design. The analogy as applied in system dynamics is a useful tool for students to model heat transfer problems with only basic knowledge of heat transfer. However, the students did not have sufficient knowledge to understand the basics of the numerical computer model to assess the reliability of the numerical calculations. Still, they were very surprised when experimental results corresponded to their theoretical simulations. It motivated them and helped them to recognize modelling as a design tool.

Keywords: Engineering education, effort, flow, system dynamics

1 INTRODUCTION

When designing a mass produced consumer good, the design should be right the first time. Mass production leaves no room for error since a lost batch of products is too expensive. Achieving this ‘first time right’ principle requires knowledge on the primary function of a product. By expressing the primary function in a parametric model, its important parameters become apparent and can be monitored throughout the production, securing the function and quality of the product. Therefore, analytical modelling skills have to become a second nature to engineers.
Industrial design engineering, however, is multidisciplinary in every way. A coffeemaker is a perfect example to show the amount of different fields that concern a design. In order to develop a coffeemaker a designer combines ergonomics, aesthetics, engineering and business aspects. The engineering itself consists of chemistry, heat transfer, electronics and hydraulics issues. All these different disciplines have to be taught at the faculty of Industrial design engineering to educate students to the appropriate level of engineers.
Industrial design engineering students often encounter problems in establishing theoretical models to predict product behaviour. The problem is not to solve mathematical equations, but to translate real life behaviour into mathematical equations. In engineering, a more scientific and analytical approach should be used to design a

working principle of a product design. Therefore, it has been decided to use a combination of system dynamics and electric circuits as a modelling tool for engineering design problems [1]. Graduation students have been encouraged to use system dynamics as a method to model heat and fluid transfer problems. In this paper, an overview of the learning process of these graduation students is given.

2 EFFORT AND FLOW ANALOGUES

In different disciplines, the entities effort and flow can be used as the physical parameters that describe the problem. In electricity, the effort and flow are defined by the voltage difference and current respectively. In mechanics, thermodynamics and hydraulics, the effort and flow become force [N] and velocity [m/s], pressure difference [Pa] and volume flow [m^3/s] and temperature difference [K] and heat transfer [W]. [1-6]
Because effort and flow always interact in the same manner, each discipline can be converted to another. By teaching one discipline and a small set of conversion rules, such as the conservation laws, the knowledge of industrial design engineering students can be expanded rapidly.

The two most common approaches are electrical and mechanical analogues. Figures 1 and 2 give two representations of the pulmonary system's impedance of dogs.

The first diagram is electrical and consists of resistors and capacitors. With these electrical representations, Kirchhoff's circuit laws, which deal with the conservation of charge and energy in an electric circuit, apply. The mechanical analogue appears quite different. Here, dashpots are analogous to resistors and springs are analogous to capacitors. However, simply replacing resistor elements with dashpots and capacitors with springs does not result in a similar system in mechanical terms.

The difference lies in the connections between the elements. In the electrical diagram, the connections between wires indicate that the current splits, while the voltage remains equal. In the mechanical analogue, connections that represent bolts or welds signify that the force splits and the velocity remains the same. Therefore, a connection in the electrical diagram requires that the effort stays the same and the flow splits, while a connection in the mechanical representation requires the opposite. Hence, the mechanical representation of elements in series is equivalent to the electrical representation of parallel elements and visa versa. An electrical diagram cannot be converted into a mechanical diagram without changing the connections, which is the reason that some terms are difficult to represent similarly in mechanical terms.

Although other types of model systems exist, none are as common as the electrical and mechanical models. Therefore, thermal, fluid, mass or other systems involving sources, resistances, capacities or inertia, are often modelled with their electrical or mechanical analogues, of which the electrical representation is by far the most popular.

It should be mentioned here, that a diagram of an electrical resistor, for instance, represents the length of a pipe, a block of material, a membrane or some other physical object that is present in the system being considered.

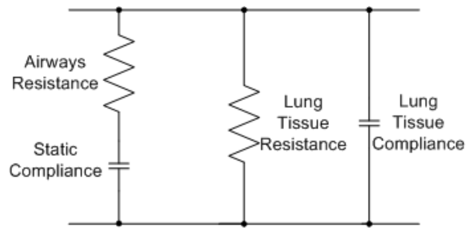

Figure 1 An electrical diagram, modelling the pulmonary system of dogs

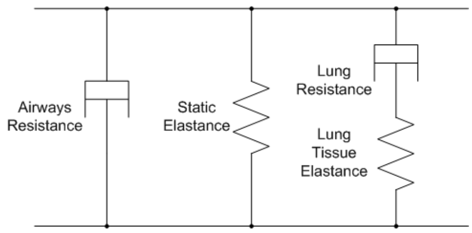

Figure 2 A mechanical diagram, modelling the pulmonary system of dogs

In the current curriculum of the IDE bachelor, students receive (obligatory) courses in electronics, which includes the different electrical components, and mechanics, which includes statics, dynamics and mechanics of materials. Our experience is that students tend to remember more about electronics than mechanics Therefore, the electrical analogy is a more obvious choice.

3 MATHEMATICS

When the behaviour of an electric circuit has to be determined, system dynamics is often used. System dynamics is an approach to understanding the behaviour of complex systems over time. Many of the system dynamics' building blocks include advanced mathematical actions, such as the Laplace transformation, which offers a more efficient way of solving differential equations. Students' lack of knowledge on mathematics in general, requires them to use computer programs for their simulations. In computer programs such as Matlab/Simulink, these mathematical building blocks can be easily applied. In addition, Matlab/Simulink includes a toolbox that provides building blocks for electric circuits, called SimPowerSystem.

However, these powerful computer programs only shift the problem, but do not actually solve it. These programs can sometimes be seen as black boxes, generating large amounts of output, without relating it to the input. When problems occur in the simulations, students are often unable to solve the problem themselves. The structured approach of following and checking each calculation step is unknown to them or they find it to be too tedious.

Furthermore, students lack the knowledge to understand the basics of the numerical model in order to assess the reliability of their calculations. Students should become more skilled in numerical modelling to be able to evaluate their results in a meaningful way.

4 TEACHING ANALOGY THEORY

In total, seven graduation students have been followed during the analysis and modelling of their product design. Six of them modelled a heat transfer problem and one

modelled a fluid transfer problem [8-10]. These students were initially unfamiliar with the analogy theory and system dynamics.
All students received one-on-one tutoring for an hour to create insight into the similarity between electricity and heat or fluid transfer. After this introduction, they derived a first model and verified it with experiments. Follow-up meetings were used to check if the first model did not contain any large errors. Depending on the stage in their design process, some students adjusted the first model or established a completely new model without any help of a tutor. Due to a lack of knowledge on advanced mathematics, simulations were usually performed with a computer program (Matlab/Simulink).
Concerning the subject material, the students first learned the physical basics of heat transfer, conduction, convection and radiation. With the use of several well-known examples, such as the sun, atmospheric windows, cooking and making coffee, the principles and models of heat transfer are explained. This includes Planck's law, which describes black body radiation, Wien's displacement law, which relates temperature to the maximal wavelength and an introduction on dimensional analysis to derive Nusselt's, Prandtl's and Reynold's number for describing convection.
Next, the analogy with electrical circuits was made by showing and explaining the striking resemblance between Ohm's law and any heat transfer formula:

$$U = R \cdot I \sim \Delta T = R \cdot \dot{Q} \quad (1)$$

It should be noted that the heat resistance coefficient must be defined in the right manner, depending on the type of heat transfer. Also, the resemblance between Kirchhoff's laws and conservation of energy is shown, together with capacity and heat capacity.
By this time, the introduction was almost over and a quick introduction into the SimPowerSystems toolbox of Matlab/simulink was given. A short example was generated on the spot to demonstrate the functionality of this toolbox.
The modelling processes of the various students showed little differences. It differed mostly in the amount of follow-up meetings, which seemed to depend on the confidence a student had in his or her own abilities.
The only student with a fluid transfer problem had trouble in adjusting the model to his own needs and drawing conclusions from it. He started by using the bond graph technique to generate differential equations that described his problem [7]. However, solving these equations turned out to be a problem, so he devised an electric diagram. Again, he encountered difficulties in simulating his problem with the use of this diagram. He did not realize what the key players in the problem were. Adjusting the diagram became an iterative process, instead of a structured process.

5 BEAT THE HEAT

In this section, one graduation case will be discussed to show how a model, based on the analogy theory, can help with designing a product. In this example, called "Beat the heat", the focus is on the diagrams that the student generated and the information she used from the simulation, in order to enhance her product design.
The assignment was the design of a suit to cool down rowers while sporting. The burning of fats and sugars during sporting releases heat, which influences the core temperature of the body. The efficiency of the human body decreases when the core temperature rises. In order to level the core temperature, the body needs to be constantly cooled. The first aspect this student modelled, was the heat transfer from the human

body to the atmosphere through convection, radiation and sweat, shown in figure 3. This model helped her to understand and get familiar with heat transfer.

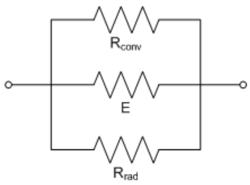

Figure 3 The heat transfer from a body to the atmosphere, using convection, radiation and sweating

Subsequently, each conceptual design was modelled and the resulting diagrams were simulated to predict its behaviour. With the use of these models, the difference between the concepts became clear and a choice was easily made. After several iterations, convection between the skin and clothes proved to be the best option for cooling the body, which was mainly due to the high heat capacity of sweat. The diagram of the final design can be seen in figure 4. Finally, experiments were performed to validate the model and the results showed that it was accurate enough to predict the behaviour and quality of the design.

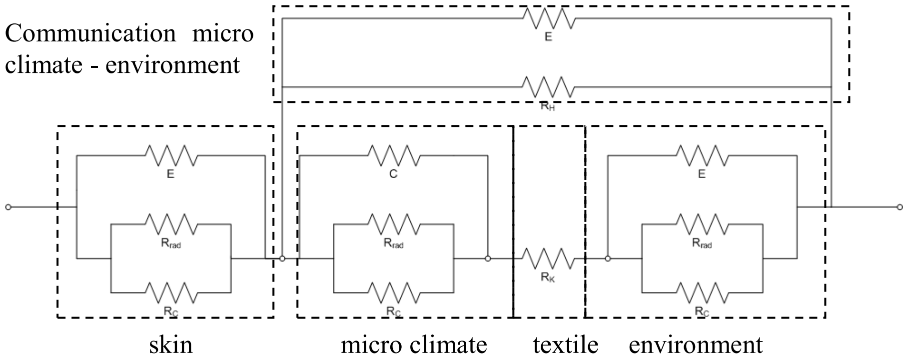

Figure 4 The heat transfer from a body through an artificial microclimate and textile to the environment

6 CONCLUSIONS

The analogy theory, as applied in system dynamics, is a useful tool for IDE students (and designers in general) for modelling heat transfer problems, while only having basic knowledge of heat transfer. This is mainly due to the fact that IDE students are already quite experienced with electronics. After a crash course, they become almost autonomous in generating the different models needed to simulate their heat problems. Although the student with a fluid transfer problem could not reach a satisfactory result, there is no reason to believe that similar results could not be expected in other disciplines as well.

Students were very surprised when experimental results corresponded to their theoretical simulations. It became clear to them that an analytical approach with theoretical simulations can have a positive effect on their designs. It not only helped them to recognize modelling as a design tool, but also greatly motivated them.

7 RECOMMENDATIONS

The type of diagrams used in this paper were always electrical, because this method suited the current curriculum and students best. However, the IDE curriculum will drastically change form September 2007 and the education will then focus on mechanics. Consequently, the models used in the analogy theory should be mechanical rather than electrical. The possibilities and difficulties of mechanical diagrams will be tested with new graduation students.

The electrical project will also be continued and it has been decided to start a new course in September 2007, which involves system dynamics. This course will be compulsory to all 225 second year bachelor students. The aim is that after attending the course, students acknowledge and are able to apply system dynamics as a useful design tool. This course, which is called ‘Modelling’, has rather ambitious goals and is currently being developed. The results will be presented at the conference.

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