Session 2166

HUMAN BIOENERGETICS APPLICATIONS IN A FLUID MECHANICS CLASS

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Abstract

Fluid mechanics is blessed with so many applications from our daily life. This paper focuses on human bioenergetics and its applications in a fluid mechanics class by giving specific examples. While some subjects are appropriate for lectures, others are more appropriate for class discussions or various types of student assignments including essays. Among many fascinating opportunities for analysis, blood flow through arteries and veins is related to the study of fluid properties, hydrostatics, pressure variation in accelerating fluids, pipe flow, and piping networks. The approach resulted in a higher level of interest and motivation, a better comprehension of the subject matter, and a higher overall satisfaction with the class.

I. Introduction

In the new millennium, engineering faculty face many challenges. One of the main challenges is to develop new curricula and pedagogy to meet the rapid development in technology. Across the country, considerable efforts have been made in recent years to make the teaching/learning of fluid mechanics more relevant and interesting to students. These efforts can be divided into the following four categories: (a) development of short open-ended design problems and classroom demonstrations/experiments [1,2]; (b) integration of courses in thermo-fluids areas into a sequence in the undergraduate curriculum [3]; (c) application of computer software to facilitate the teaching of fluid mechanics [4]; and (d) adoption of multi-media and computer-based textbooks to promote active learning. To further such efforts, we have explored the feasibility of using circulatory system in human bodies to illustrate basic principles in fluid mechanics. The effort started in the spring of 2001.

Most fluid mechanics textbooks traditionally rely heavily on mathematics and abstract concepts. Examples and problems in these texts usually focus on areas of transportation and industrial processing which are unfamiliar to many sophomore and junior engineering students. Such a situation often created a misconception among students that learning the subjects is to memorize equations, and doing the homework is just a “plug-and-chug” process in manipulating equations. To change this mindset and to enhance the effectiveness of learning, new examples and problems are needed. These examples and problems must be relevant to the objectives of the course, interesting and stimulating to students, and closely related to their daily experience. Among many fascinating opportunities for studies, blood flow through arteries and veins seems to fit the requirements.

The circulatory system in human bodies consists of a pump (heart), blood (fluid), and blood vessels (piping networks). The operation of the system follows the fundamental laws of fluid mechanics.

Subjects in undergraduate fluid mechanics, such as fluid properties, hydrostatic effects, variation of fluid pressure in pipes, piping networks, and pump and piping system characteristics, can be related to problems from the cardiovascular system in human bodies. Moreover, using topics from human body to illustrate principles of fluid mechanics would arouse students' interest because such topics are directly related to their well-being and own experience.

This paper will present a brief report on our effort in developing such an approach. The effort can be divided into two stages. The first is the planning stage where we identified appropriate subjects and developed pedagogical methods for integration. The second is implementation of the plan. A brief account of the work in these two stages is as follows.

II. Planning

In the planning stage, we encountered two main challenges. The first concerns with content material, i.e., what topics are suitable to be included in the course. The second concerns with pedagogy, i.e., how to integrate these topics to the already large amount of course material in fluid mechanics.

a) The Content Issue

Just like many colleagues in mechanical engineering, we do not have formal educational backgrounds in the field of human physiology. To overcome this handicap, in the summer of 2001 we made an effort to familiarize ourselves with this new subject, especially on the circulation of blood in human bodies. We found the learning experience to be very rewarding and stimulating; and the learning curve to be fairly steep. This pleasant experience in learning the subject further convinces us that the approach would be very promising. To broaden our horizon, we also examined existing course syllabus from various biological engineering programs across the country. From these efforts we considered the following topics as relevant to our course.

(1) Physical properties of blood. Relevant subjects may include the concept of Newtonian and non-Newtonian fluid; factors affecting blood viscosity and its effect on health.

(2) Pressure variation in circulation system. The pressure variation is subjected to the effect of viscosity and weight of the blood, as well as the effect of acceleration in the blood flow. Thus, a number of phenomena and diseases in circulatory system can be explained using the basic principles of hydrostatics, the Bernoulli equation, and head losses in pipe flow.

(3) Blood flow and its regulation. Blood flow can be classified as laminar or turbulent. The volumetric flow rate is affected by pressure drop, properties of the blood, and the diameter of blood vessels. The effects of physical activities and blood vessel diseases on blood pressure and flow rate provide a number of interesting examples to show the application aspect of theories in laminar and turbulent pipe flows.

(4) The circulation system. The blood vessels can be classified into three main groups, i.e., the arteries, capillaries, and veins. The arteries carry blood pumped by the heart to the tissues by smaller arteries (arterioles) and capillaries. Blood is returned to the heart by smaller veins and then

to larger veins. It is possible to use the circulation system in human bodies to illustrate the flow distribution and regulation in piping networks.

(5) Interaction between the heart and the blood vessels in the human cardiovascular system. In piping system, fluid flow rate and head developed by a pump are determined by the pump characteristics and system curve. The same principle can be used to determine the pressure and flow rate produced by the heart. With this approach, one can understand the effects of various heart or vascular system maladies on blood pressure, flow rate, and work done by the heart.

b) The Pedagogy Issue

The method of integrating the content materials mentioned above into the fluid mechanics course is very important because the purpose of this approach is to enhance students' learning instead of overburdening them. We found that there are at least four venues for integration.

(1) Lecture. The lecture will be benefited greatly if one can relate students' life experience to illustrate some key concepts in fluid mechanics. A number of phenomena in human circulation system are easy to understand, and can be presented mostly in qualitative terms. We believe using these phenomena as examples in lectures will help linking fluid mechanics to biological science, and dispel the misconception among students that the subjects of fluid mechanics are too abstract and boring.

(2) Discussion. Some problems in human circulation system appear to be more complicated and the solutions of these problems do not seem to be obvious to students. This type of problems can serve as puzzles to be discussed in lectures. The discussion can promote active student participation in the classroom and help them gain a deeper understanding of subject matters.

(3) Demonstrations. Certain phenomena in circulation system are both easily observable and related to fluid mechanics. Effective use of these phenomena as demonstrations would bring a lively atmosphere in the classroom and help inspire students to learn the subject.

(4) Homework or projects. Some blood problems are suitable for more in-depth study and can thus be used as homework or projects in the course. In our classroom experience, we noticed how merely mentioning such topics immediately captured the student's attention and galvanized their interest unlike anything we had seen before. Working through this type of projects would provide a deeper insight to some key concepts in fluid mechanics.

III. Implementation

The plan mentioned above was implemented in the fall semester in 2001. In our initial trial we focused on how to integrate relevant blood flow problems in classroom activities, including lectures, discussion, and demonstrations. In the future we will expand the effort to include homework and projects.

a) The Current Effort - Using Blood Flow Examples in Classroom Teaching

We started the new approach in the fall of 2001. As an initial trial we used only a limited number of blood flow subjects in our teaching. A brief account of these subjects is as follows.

(1) Fluid properties. We investigated the cause of frostbite to illustrate the effect of temperature on fluid viscosity. It is well known that blood under low temperature would significantly increase its viscosity, leading to reduction of blood flow to the affected areas and causing frostbite. In addition to temperature, another factor that affects the blood viscosity is the concentration of red blood cells. Since cigarette smokers usually have higher level of red blood cells in their blood than non-smokers, their blood usually has higher viscosity. Such elevated viscosity leads to more cardiovascular disease for smokers.

(2) Hydrostatic pressure. When we covered the subject of variation of pressure in static fluid, we pointed out that the same principle plays an important role in blood pressure as well. When the human body is in a horizontal position, the mean arterial pressures in the brain and the feet are approximately the same. When the body is erect, the hydrostatic factor reduces the arterial pressure in the brain and increases that in the feet. If a person's cardiovascular reflexes (for adjusting to change in posture) are inadequate, he/she feels dizziness and might even faint. We also use a simple demonstration to illustrate the hydrostatic principle. We first asked the students to put their hands to a position lower than their hearts to observe that the veins on the back of their hands stand out. Next we asked them to raise their hand above the level of the heart, and then they would see that the veins collapse. Such a demonstration helped make students to be more observant, and showed them the relevancy of the subject matter.

(3) Pressure variation in an accelerating fluid. After presenting the topic of pressure variation in a tank of liquid with uniform acceleration, we asked students to calculate the acceleration limit (in the direction against gravity) in the design of roller coasters. This limit is to prevent passenger 'black out' caused by the effect of pressure variation in accelerating fluid. Beyond that limit the passenger's heart would not be able to deliver blood to the brain, creating a serious safety issue. Students can further the study by devising methods to alleviate similar problems in space flight.

(4) Pipe Flows. In discussing Poiseuille's equation, we asked students to apply the equation to explain how narrowing blood vessel and increasing blood viscosity, caused by smoking and high blood cholesterol level, would lead to high blood pressure, and subsequently cause heart troubles and other diseases. Such knowledge further convinces students to form good dietary habits and quit smoking. We also let students discuss whether the circulation of blood would be affected by the change of posture from horizontal to erect. Intuitively many students thought it would. Later they found that the intuition is against the energy and continuity equations. The conclusion is that it would affect the circulation, but only temporarily. When a person changes his posture from horizontal to erect, the elevated blood pressure in the foot (produced by hydrostatic effect) would dilate the blood vessel and increase the storage capacity there. From continuity equation the return flow to the heart would be temporarily reduced until steady state is reached. This discussion cleared some misconception in pipe flow problems.

The result of the initial trial is very encouraging. We are in the process of developing more examples, discussion topics, and demonstrations for future classroom teaching.

b) Future Effort - Development of Homework Assignments and Projects

We plan to develop several open-ended projects for use in the course. The addition of this component to the course would strengthen our efforts to integrate design throughout the curriculum. Tentatively we identify the following topics for consideration.

a. Human circulatory system and piping networks. Students would examine the major components of the cardiovascular system and then draw a schematic diagram of equivalent piping network to represent the circulatory system. The result would be a closed-loop piping network consisting of pipes of various lengths and diameters. Methods for piping network analysis can be used to determine the mean pressure changes across the vascular circuit and the result would be compared with measured results found in literature. Since physical exercise would trigger the contract/dilate mechanism to enlarge the diameter of blood vessels to working muscles, students can also use the piping network theory to analyze the effect of physical exercise on the distribution of blood flow in the vascular system. A simplified computer model can be developed to facilitate the studies.

b. Pump (heart) – piping (blood vessels) system operation. The cardiovascular system consists of two major circulatory systems (i.e., pulmonary circulation and systemic circulation) and the heart - a double pump. Similar to pump-piping systems, the operation of cardiovascular systems is determined by the characteristics of the heart and the blood vessels. Students can investigate how physical activities would modify these characteristics and subsequently affect the operating point of the system. After determining the operating point, students can use the flow rate and the head to calculate the work done by the heart. They can also expand the study to include problems associated with the effect of heart enlargement and leaky heart valves on system performance.

IV. Closure

As explained in Section III above, this is an ongoing project. Based on our experience so far, we anticipate that the use of cardiovascular system phenomena as examples could benefit a fluid mechanics course in the following ways:

- Show the relevancy of the fluid mechanics. Using basic principles of fluid mechanics to explain certain phenomena in human bodies dispels the misconception that these principles are abstract and boring. Thus the approach helps convince students about the need to study fluid mechanics and thus motivate them to attain greater achievements.

- Broaden the scope of learning. This approach develops the student's ability in lateral thinking by exposing them to some interdisciplinary topics. In the 21st century, more and more engineers would be required to work on interdisciplinary projects that would require them to integrate ideas and methods among seemingly disparate fields.

- Enhance the learning of basic concepts in fluid mechanics. Problems in cardiovascular systems provide excellent examples to illustrate basic concepts in fluid mechanics. These examples are familiar to students and appropriate for integration with classroom teaching. Such integration not only makes the course more interesting, but also increases student's awareness on some important health issues.

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