Using Animations to Enhance Understanding of Energy System Concepts

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Abstract

Traditional engineering education presentations use static pictures/illustrations to visualize/demonstrate various concepts, some of which can be quite involved. In many instances, the sequence of static pictures is interspersed with explanations to deepen understanding of the physical concepts. Since animation software and animation development are becoming less expensive and more common, animations that will reduce lecture time devoted to a topic and enhance student understanding are becoming more affordable.   Animations permit salient features of phenomena to be combined in a readily visible fashion for understanding. This paper will explore the effectiveness of an animation example taken from an energy systems design course and examine in detail the water hammer animation since it is a good example that illustrates many facets of water hammer. All of the salient features of water hammer can be shown on a static illustration/diagram, but the animation in more effective in demonstrating the scope of the water hammer phenomena. Cognitive issues for enhancing animation effectiveness will be examined. Student survey results and instructor anecdotal experiences comparing the effectiveness of the animations as compared to traditional static coverage will be discussed. Student survey results confirm that the water hammer animation was successful in enhancing understanding.

Introduction

Traditional engineering education presentations use static pictures/illustrations to visualize/demonstrate various concepts, some of which can be quite involved. In many instances, the sequence of static pictures is interspersed with explanations to deepen understanding of the physical concepts. Since animation software and animation development are becoming less expensive and more common, animations that will reduce lecture time devoted to a topic and enhance student understanding are becoming more affordable. Indeed, an examination of ASEE Annual Meeting and Exhibition proceedings and ASEE Frontiers in Education Conferences for the last few years indicate an intensive interest in animations in virtually all ASEE divisions. The Mechanical Engineering Division is no exceptions, although the emphasis on papers devoted to animations has not been as strong as in many other divisions. In addition to "how to" and "example" papers, the pedagogical literature relating to animation effectiveness has increasingly focused on cognitive issues. The next few paragraphs provide an overview of typical, but not inclusive, papers and archival journal articles related to animations.

ASEE references include conference papers and articles in ASEE-sponsored archival publications such as the *Journal of Engineering Education* and *Computers in Education*. Typical conference paper examples include Shen and Zhu [1], Giro et al. [2], Abulencia et al. [3], Balazinski and Przybylo [4], Ziegler [5], and Hoorfar et al. [6]. These papers generally discuss in detail the structure of the animations involved and present some assessments, perhaps anecdotal, of how effective the animations were in conveying the salient features of the phenomena. The time scale is about a decade, indicating the length of time of animation involvement by ASEE members. Typical archival journal articles are Hoorfar et al. [7] (the journal version of [6]); indeed, many of the *Computers in Education* articles originated as ASEE conference papers. While the *Journal of Engineering Education* contains some articles related to

animation issues, the focus of the journal is engineering education research. However, the mission of the ASEE *Advances in Engineering Education* is to disseminate innovations in engineering education practice, especially those demonstrating creative uses of multimedia. Examples of recent animation-related offering include DeLale et al. [9] and Cameron et al. [10]. Generally, the *Advances in Engineering Education* articles contain specific details of topics and applications and tend to be longer that either conference papers or other ASEE-sponsored journal offerings. The purpose of this paragraph is to demonstrate the extensive ASEE literature on animation as well as the level of long-term interest exhibited by the ASEE community.

Obviously, animation in education is not limited to engineering education. In recent years, pedagogical issues and strategies have emerged as primary topics related to animation. In particular, the idea effective use of animations via consideration of cognitive issues has been addressed. As this issue directly impact the animations discussed in this paper, an examination of some of that literature is appropriate. References [11]-[15] are typical citations pertaining to cognitive issues in animation effectiveness from the non-ASEE community. These references are from psychology-based journals, not engineering education-based journals. Yarden and Yarden [11] is a particularly useful article as it both reviews cognitive animation issues and offers suggestions for improving animation effectiveness.

Yarden and Yarden [11] offer a comprehensive review (containing fifty-eight citations) and assessment of the cognitive literature related to animation effectiveness. Even though they specifically address issues related to animations in biotechnology, the suggestions they make and the conclusions they reach are generally applicable to engineering education. A primary point is that contrary to expectations, using animations does not ensure learning. Animations with high cognitive loads cause students to miss essential features. Yarden et al. propose a three-tiered approach to generating effective animations: (1) use the cognitive basis of learning in developing visualization tools, (2) support students' learning with animations, and (3) acknowledge the teacher's role in effectively presenting animations in a class-room setting. The key to the first item is that humans possess different channels for processing visual and verbal representations so that information encoded in both channels will be better mastered than in either channel. Thus, narration with the animations is proposed. Moreover, they point out that only a few pieces of information can be processed at one time leading to animations with reduced cognitive loads. Not surprisingly, more learning occurs when the learner is actively engaged. Item two suggests that students learn new concepts by relating the new information with concepts they already understand. The instructor thus plays a critical role in understanding and assessing the existing student knowledge base in order to formulate an effective animation and to relate the animation to already understood concepts—the essence of item three. Yarden et al. also recommend that animations be stopped and started to permit reinspection and focusing on specific parts. Speeding up and slowing down as well as alternatives perspectives tend to facilitate more effective learning from animations. They propose that presenting animations after introductory information has been discussed permits students to better cope with the details.

The discussion demonstrates the wide dissemination of materials related to animations in engineering education and the cognitive basis of making animations more effective. The next section presents details of how an animation demonstrating the important features of water hammer was developed and used in ME 4333/6333 Energy Systems Design in the Mechanical Engineering program at Mississippi State University.

Water Hammer Fundamentals

ME 4333/6333 Energy Systems Design is a required capstone thermal systems design course in the Mechanical Engineering program at Mississippi State University. It is also available as a technical elective for non-ME undergraduates and for graduate credit for graduate students who have not completed a thermal systems design course. A number of papers, such as Hodge [1998], have been presented on details of the course and a textbook, Hodge and Taylor [1999], has been in print through three editions for more than a quarter of a century.

The last topic covered in ME 4333/6333 and the last chapter in Hodge and Taylor are devoted to transient flow in pipes. Rigid theory and water hammer are covered, and the method of characteristics for water hammer analysis is briefly examined. Rigid theory is based on the dual assumptions of incompressible flow and a rigid pipe. The speed of sound is unbounded for an absolutely incompressible fluid, and a rigid pipe wall does not interact with the flow. Rigid theory is mathematically relative simple; the differential equation is variable separable if the friction factor is taken as constant. Since the speed of sound is unbounded, an event at any location is the flow field is instantaneously communicated to all point is the flow field. Water hammer, on the other hand, considers the fluid as compressible and the pipe wall as elastic. For an unbounded fluid, the speed of sound is given by

$$a = \sqrt{\frac{K}{\rho}} \tag{1}$$

where K is the bulk modulus of the fluid and ρ is the density. Water at standard temperature possesses a speed of sound of near 5000 ft/s—much higher than the speed of sound in air at standard temperature, about 1100 ft/s. For fluid in a confined area, such as a pipe, the speed of sound or the water hammer wave velocity is

$$a_s = \sqrt{\frac{K}{\rho \cdot \left(1 + \frac{K}{E} \cdot c\right)}} \tag{2}$$

where E is Young's modulus of the pipe material and "c" is a constant that depends on the pipe's elastic properties and constraints. For a schedule 40 6-inch nominal pipe, the water hammer wave velocity is about 4400 ft/s for typical constraints.

Thus, for a confined flow, as in a pipe, the speed of sound is a function of the fluid, the pipe material characteristics and the pipe constraints. Since a disturbance propagates at the speed of sound, water hammer is a wave phenomena in which the water hammer wave interacts with the elastic pipe. Water hammer is, thus, mathematically more complex than rigid theory. The method of characteristics is the usual technique for water hammer analysis. However, the purpose of this paper is to use animation to help student understand the salient features of water hammer.

As part of the discussion on water hammer, the traditional static presentation illustrating the evolution of a simple, frictionless water hammer progression is described. Figure 1 from Hodge and Taylor [1999], originally from Watters [1979], has traditionally been used in ME 4333/6333. In the figure, the fluid steady-state speed is V and the water hammer wave velocity is a. Important features of the water hammer evolution are as follows:

t = 0   The valve at the end of pipe with a flowing fluid is suddenly closed, initiating a compression water hammer wave (speed a) that travels from the closed value upstream toward the pipe entrance.

$t = 1/2 \cdot L / \cdot a$ The water hammer wave is half way between the valve and the pipe entrance. The fluid to the left of the water hammer wave is flowing to the right with the steady-state velocity, V; the fluid after the passage of the wave is at rest, but the head is increased by ΔH and the pipe wall distended because of the increased pressure.

$t = L/a$ The water hammer wave has reached the pipe entrance where the compression wave is reflected as an expansion wave. The fluid in the pipe is at rest, but the pressure is increased and the pipe wall distended.

$t = 3/2 \cdot L/a$ The expansion wave (the compression wave reflected from the free surface) is moving to the right and is half way between the pipe entrance and the valve. The fluid, moving to the left, possesses a velocity V; the pressure is decreased, and the pipe wall is relaxed after passage of the expansion wave. The fluid before the passage of the expansion wave is at rest, but the head is increased by ΔH and the pipe wall distended because of the increased pressure.

$t = 2 \cdot L/a$ The expansion wave has reached the valve where the expansion wave is reflected as an expansion wave (a wave reflected from the solid surface reflects as the same type of wave). The fluid in the pipe is moving to the left with a velocity V, but the head is decreased and the pipe wall no longer distended.

$t = 5/2 \cdot L/a$ The expansion wave (the expansion wave reflected from the solid surface) is moving to the left and is half way between the pipe entrance and the valve. The fluid behind the wave is at rest; the head is decreased, but the pipe wall diameter is decreased after passage of the expansion wave. The fluid before the passage of the expansion wave is moving to the left.

$t = 3 \cdot L/a$ The expansion wave has reached the pipe entrance where the expansion wave is reflected as a compression wave from the free surface. The fluid in the pipe is at rest, but the head is decreased and the pipe wall diameter is decreased.

$t = 7/2 \cdot L/a$ The compression wave (the expansion wave reflected from the free surface) is moving to the right and is half way between the pipe entrance and the valve. The fluid behind the wave is moving to the right at velocity V; the head is increased, and the pipe wall diameter is increased after passage of the compression wave. The fluid before the passage of the

compression wave is at rest.

t = 4·L/a   The compression wave has reached the valve, the fluid is moving to the right with a velocity V, and the head is at the original value. But these are the conditions as at time t = 0! The cycle will, thus, be repeated at a 4·L/a frequency. Friction will eventually damp out all the waves, and the fluid will be at rest.

A lot is happening in the sequence presented in Figure 1, and significant explanations and repetitions are necessary to convey all the salient features. These features include:

- traveling water hammer waves

- pipe distensions for compression and expansion waves

- waves reflections from solid walls as well as free surfaces

- periodical nature of some water hammer scenarios

- identification of compression and expansion waves.

- wall/fluid interactions

The animation discussed in the next section was developed to help students assimilate the various features and in accordance with suggestions contained in Yarden and Yarden [11].

Water Hammer Animation

The water hammer animation was designed to accelerate the learning curve of students. All the features statically illustrated in Figure 1 are incorporated into the animation. The animation is dynamic in that the wave motion, pipe wall distensions, wave reflections, and time are included in a time-dependent "movie." Several screen shot captures will be used to illustrate the animation appearance. During the presentation, the animation in will be demonstrated. The suggestions of Yarden et al. [11] have been utilized to avoid cognitive overload and enhance understanding.

Figure 2 is a screen shot from the animation at t ≈1/2·L/a. All the salient features of Figure 1 at t =1/2·L/a are present, but the animation has at this point illustrated the wave moving from the valve to the midpoint of the pipe. The first showings of animation are at a slow speed so that the instructor can explain the features without cognitive overload.

Figure 3 is a screen shot from the animation at t ≈3/2·L/a. All the salient features of Figure 1 at t =3/2·L/a are present, but the animation has at this point illustrated the wave reflecting from the free surface at the reservoir. The expansion wave passage results in a decrease in the pipe diameter. Figures 4 and 5 are screen shots at t ≈5/2·L/a and t ≈7/2·L/a. They are congruent with the times in Figure 1 and demonstrate the same features, but in a time-dependent fashion.

The approach used is to run the animation at a slow speed with narration by the instructor several times pointing out important features. The first showing is the complete 4·L/a time cycle, but with attention only to the wave passages; subsequent showings add details and point out additional features to avoid cognitive overload if all were features were presented in a single demostration. In order the make the point of the speed of water hammer, the animation is then

shown with little narration, but speeded up to capture the flavor of the speed of the water hammer phenomenon.

Water Hammer Animation Assessment

The water hammer animation was presented in the ME 4333/6333 class on 28 November 2012. After presenting and narrating the animation as described in the previous section, a survey was used to help assess the effectiveness of the water hammer animation as opposed to the traditional static presentation and discussion of Figure 1. The assessment tool, reproduced in Figure 6, permits some quantitative assessment metrics to be determined. Eight questions were in the survey: Questions 1-3 and 6-8 were true or false and Questions 4 and 5 were Likert-scale based. Thirty of the forty students in the class participated in the survey. As Table 1 indicates, the student responses were overwhelmingly positive for the true-false questions. Questions 1 and 2 responses infer that the animation approach was superior to the static presentation approach in terms of water hammer understanding. Question 3 confirmed that the narration as suggested by Yarden et al. [11] played a key role in understanding the details presented in the animation. Questions 6-8, not surprisingly, acknowledge the students' preferences for something other than conventional lecture.

Questions 4 and 5, the Likert-scale questions, permit some assessments to be made about the level of understanding of the details of the salient features of water hammer. Most student responses show that the animation was effective in emphasizing salient features that might be missed in the conventional static approach. The Yarden et al. [11] suggestions of multiple showings coupled with narration are confirmed as effective in avoiding cognitive overload for this animation.

In conversations with students after the animation presentation, the positive anecdotal responses of the students to the instructor were confirmed: the animation was successful in terms of enhancing student understanding of water hammer when compared to the traditional static presentation and discussion.

Conclusion

Based on both the survey results and the instructor's anecdotal discussions, the water hammer animation was successful. Indeed, the success of this initial animation endeavor is strong motivation to increase the use animations in this course (as well as other courses taught by the authors).

Many topics of interest in the thermal sciences can be shown on a static illustration/diagram, but animation is more effective in demonstrating the scope of the water hammer phenomena. Indeed, in a likely forthcoming new edition of an energy system design textbook [17], animations are to be included in the instructor support material available from the publisher.

The authors estimate that thirty-forty animations could be effectively used in the energy systems design course. In a semester that is about an animation presentation per lecture (MWF format). Thus, use of an animation per lecture period provides another "change in focus" to separate different classroom activity sequences that enhance student attention and comprehension.

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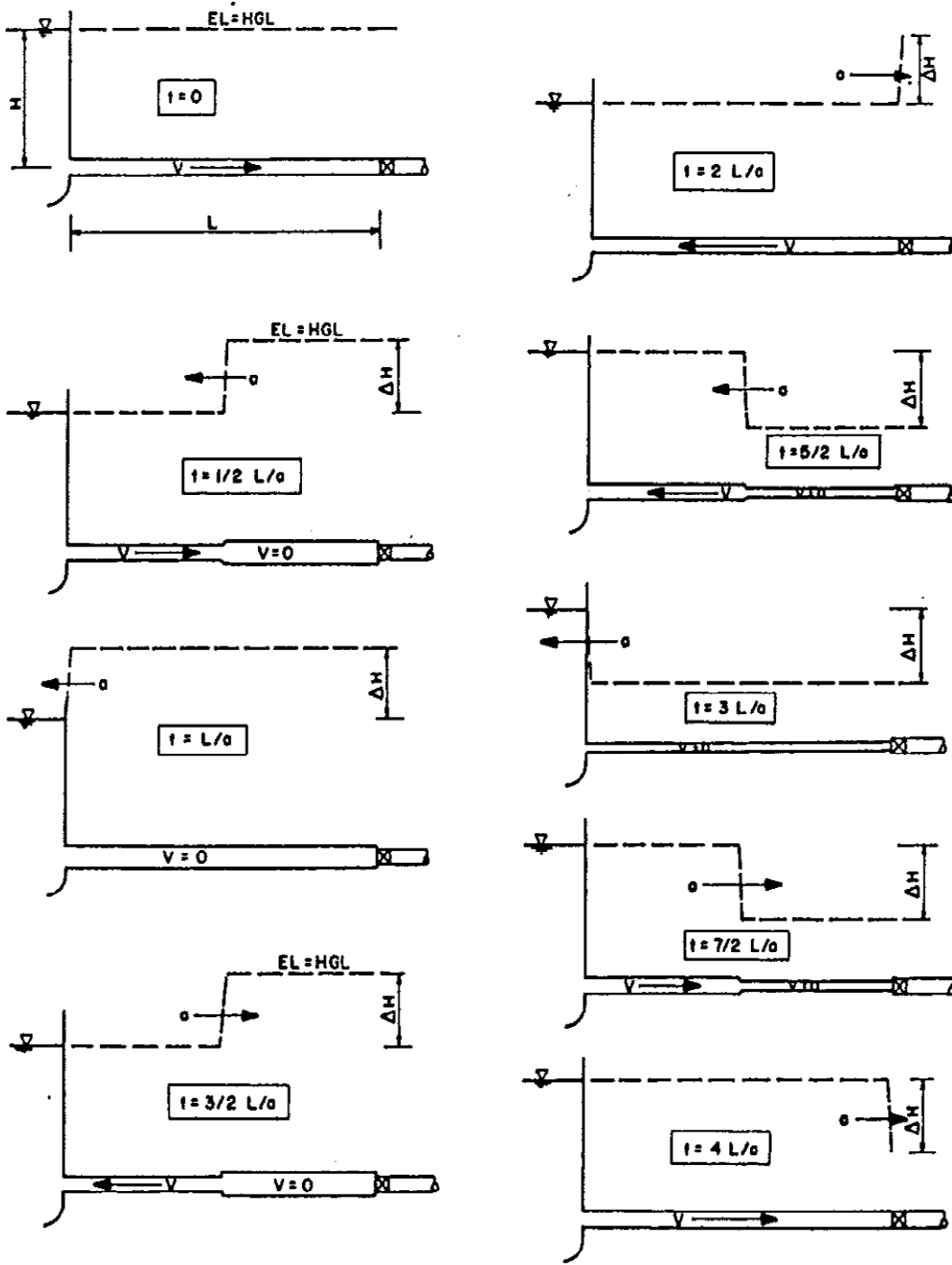
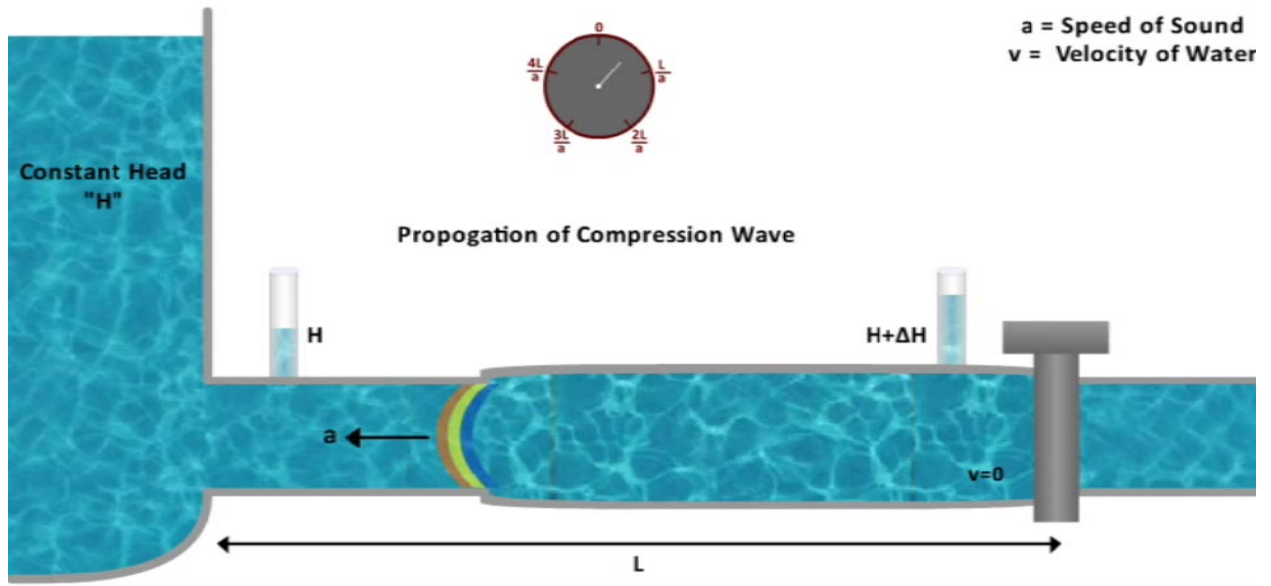Figure 1. Water Hammer Evolution from Hodge and Taylor [17] by Watters [18].

Figure 2. Animation Screen Shot at t ≈ 1/2·L/a.

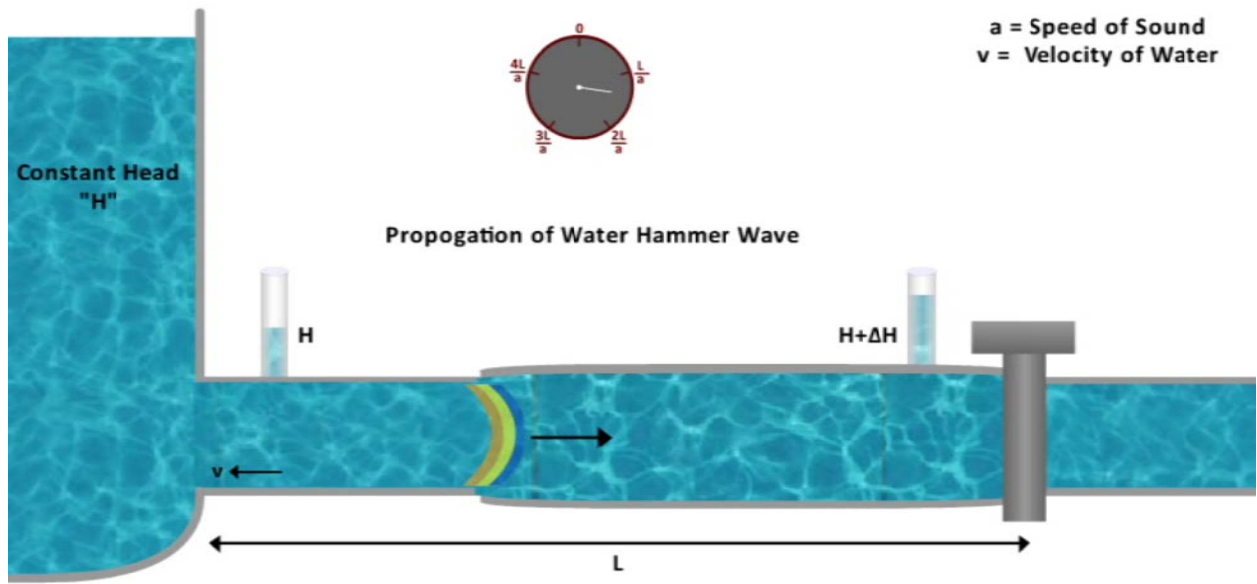Figure 3. Animation Screen Shot at t ≈ 3/2·L/a.

a = Speed of Sound
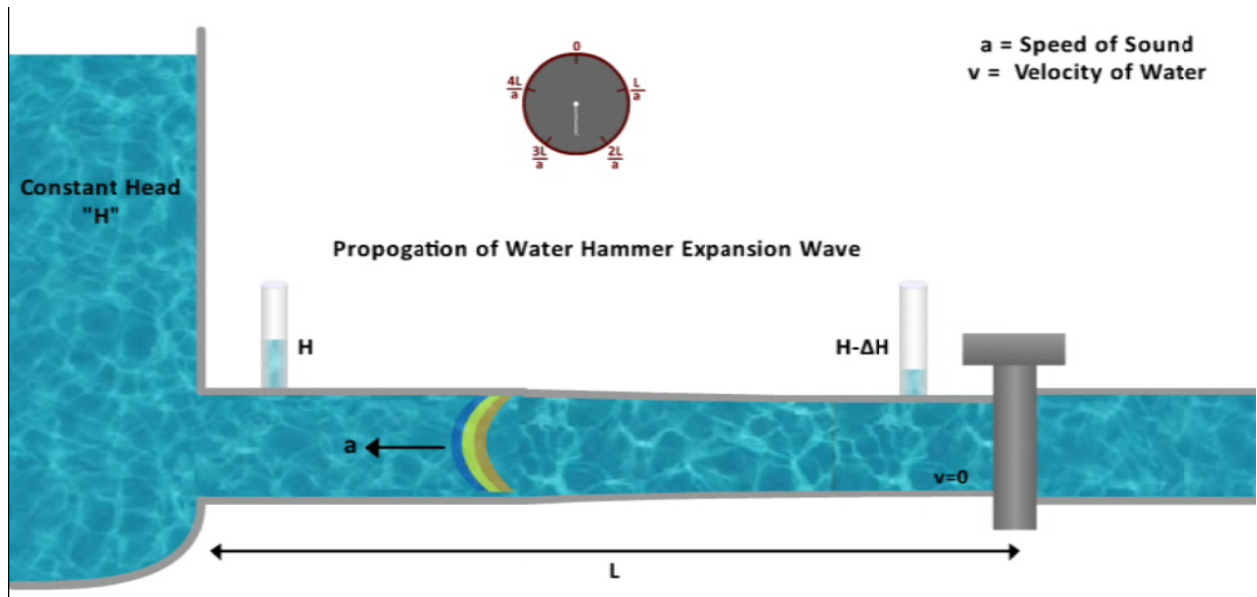v = Velocity of Water

Propogation of Water Hammer Expansion Wave

Constant Head
"H"

H

H-ΔH

a

v=0

L

Figure 4. Animation Screen Shot at t ≈ 5/2·L/a.

a = Speed of Sound
v = Velocity of Water

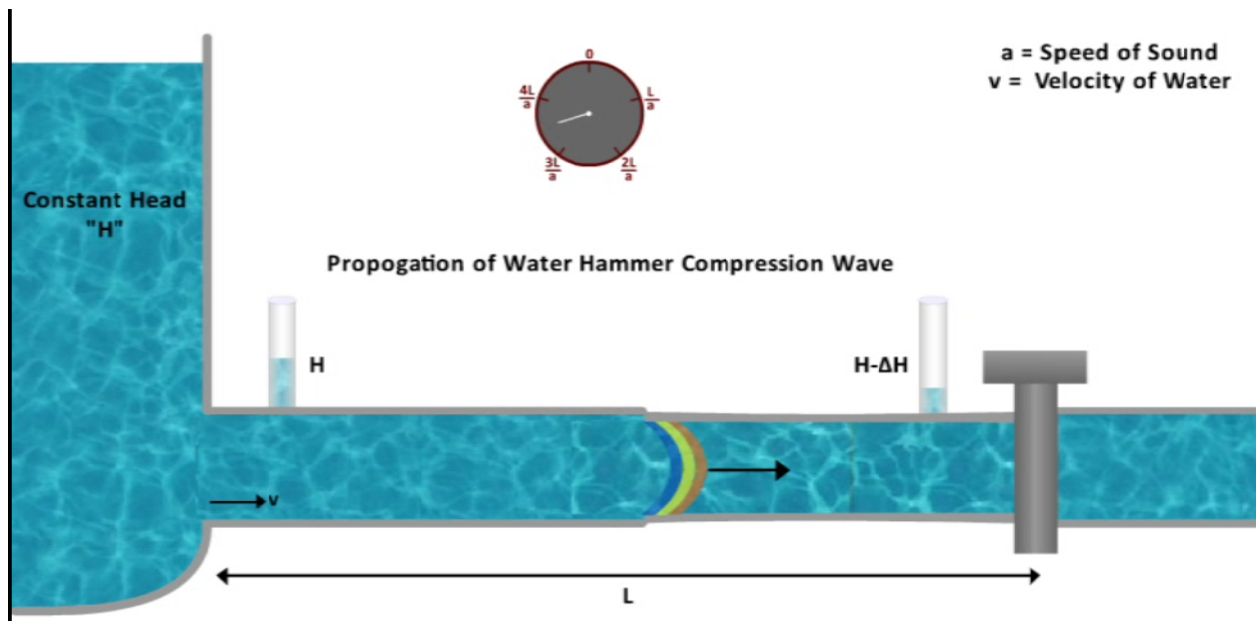**Propogation of Water Hammer Compression Wave**

Constant Head
"H"

H

H-ΔH

v

L

Figure 5. Animation Screen Shot at t ≈ 7/2·L/a.

ME 4333/6333 Animation Effectiveness Survey
Fall 2012

1. Teaching water hammer through animation was more effective than using the static presentation.

_____ True   _____ False

2. Using the water hammer animation in class made understanding the details of water hammer easier than in the static presentation.

_____ True   _____ False

3. The narration by the instructor was key factor in enhancing the effectiveness of the water hammer animation.

_____ True   _____ False

4. Were you able to relate the time on the "clock" with the direction and nature of water hammer wave propagation?

Never	Rare	Sometime	Most of Time	Always
1. _____	2. _____	3. _____	4. _____	5. _____

5. Were you able to relate pipe distention with the nature of wave propagation?

Never	Rare	Sometime	Most of Time	Always
1. _____	2. _____	3. _____	4. _____	5. _____

6. More animations would be useful in Energy Systems Design.

_____ True   _____ False

7. The use of animations makes classroom activities more interesting.

_____ True   _____ False

8. The use of animations promotes more effective learning in the classroom.

_____ True   _____ False

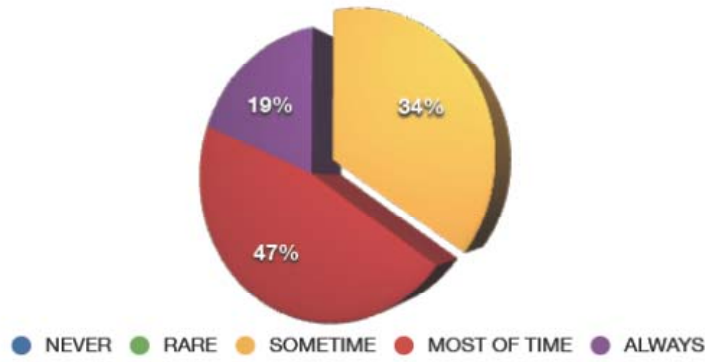Figure 6. Student Survey to Assess the Water Hammer Animation Effectiveness.

Figure 7. Student Survey Results for Question 4.
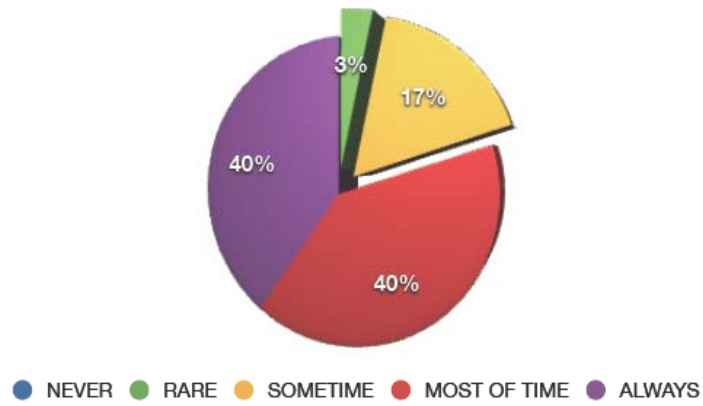

Figure 8. Student Survey Results for Question 5.

Table 1. Student Survey Results for Questions 1-3 and 6-8.

	TRUE	FALSE
Question 1	30	0
Question 2	29	1
Question 3	27	3
Question 6	30	0
Question 7	28	2
Question 8	29	1