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DEMONSTRATION OF THE USE OF MULTIMEDIA ELECTRONIC INFORMATION ENHANCEMENTS FOR A CHAPTER HANDBOOK CD-ROM (1017 RP): OVERVIEW

Ergun Akleman, Ph.D. **Jeff S. Haberl, Ph.D., P.E.** **Frederic Parke, Ph.D.**
ASHRAE Member
Sajan Skaria **John Halstead** **Malcolm Andrews, Ph.D.**

Abstract

A set of enhancements to the ASHRAE Handbook [1] are presented to demonstrate the effectiveness of multimedia and advanced presentation techniques such as 3D computer graphics, visualization and animation techniques. These results can also serve as a model and guide for the broader use of these techniques in other ASHRAE publications.

1 General Introduction to Project

In this paper, we present a set of enhancements to the ASHRAE Handbook [1] that demonstrate the effectiveness of multimedia and advanced presentation techniques such as 3D computer graphics, visualization and animation techniques. This demonstration is also meant to serve as a model and guide for the broader use of these techniques in other ASHRAE publications. The enhanced chapter is intended to be used in the CD-ROM version of the Handbook, which is also posted on ASHRAE's Web site, and can be used in other ways to promote the effectiveness of improved presentation techniques, and the value of ASHRAE information resources. Using compressors as the subject, the research project 1017 expanded on the material contained in Chapter 34 of the HVAC Systems and Equipment Handbook.

Chapter 34 covers various types of compressors such as centrifugal, scroll, rolling piston and twin-screw [1] that are used for heating, refrigerating and air conditioning. For engineers it is essential to understand how each type of compressor works as well as how to use technical charts and graphs to analyze and design a system. Unfortunately, it is almost impossible to understand the working principles of compressors just by looking at static 2D illustrations. It is therefore essential to create various multimedia solutions that can show how compressors work. The multimedia solutions that were developed include the following:

1. Animations that show how the individual parts of compressors move during compression cycles.
2. Animations that show how the fluid moves through compressor during compression.
3. Sound effects that demonstrate the noise compressors make during different modes of operation.
4. Interactive diagrams that indicate the various stages of compression cycles.
5. Animations that show the detailed fluid dynamics using Computational Fluid Dynamics (CFD).

This work includes these multimedia solutions and other advanced visualization methods for electronically presenting information. To accomplish this we used primarily widely available, non-proprietary, platform-independent presentation tools, which also allows the enhanced handbook to be made available over the internet. This enhanced version of Chapter 34 is organized as an HTML hypertext document where figures are linked into and form an integral part of the document. These figures are implemented as GIF [2] or JPEG images [3], two-dimensional and three-dimensional Quicktime animations [4], interactive JAVA applets [5], or as three-dimensional VRML models [6].

2 Background and General Introduction to Computer Graphics

All advances in multimedia presentations have their roots in the field of computer graphics. Computer graphics, a relatively new field, has advanced so quickly that it is difficult to summarize the advances accomplished by computer graphics research and development in a few pages. An extremely brief historical timeline of computer graphics can be found in [11].

The following are basic computer graphics terms (or subjects) that are useful to understand the stages of computer graphics production.

- *Digital Image:* It deals with subjects such as image formats, image compression and image manipulation. Image formats such as Graphics Interchange Format (GIF) [2] and Joint Picture Expert Group (JPEG) [3] that have been developed to efficiently compress the image data without any visible loss of quality are the subject covered by digital image and are extensively used in this work.
- *Shape modeling:* This deals with creating, representing and manipulating 3D shapes. Modeling is a very broad subject and requires much effort to learn. Fortunately, for ASHRAE applications most modeling problems can be simplified. For instance, the parts of compressors can usually be modeled with solid modeling by using set operations (i.e. union, intersection and set difference [9, 10]) over primitive shapes.

An example of set operations is shown in Figure 1 for two separate cylinders (Figure 1.A), the union of two cylinders (1.B), the intersection of common volumes of both cylinders (1.C) and the set difference (1.D). Since engineers are familiar with set operations, it should be easy for ASHRAE members to understand modeling with set operations. In some cases such as the screw shape found in twin-screw compressors, there is a need to use more complicated modeling approaches such as extruded surfaces.

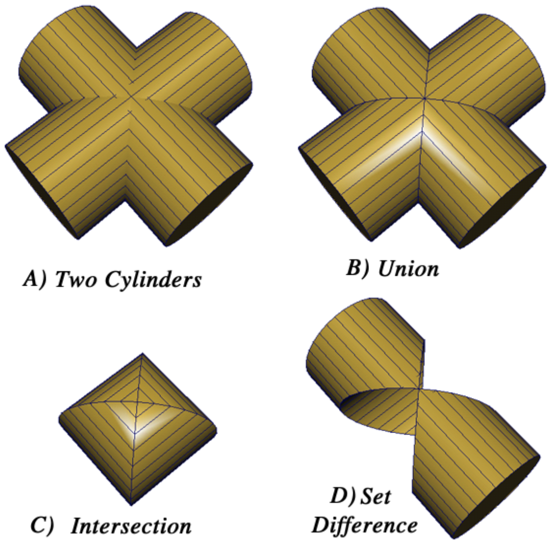


Figure 1: An example of set operations: Union, intersection and set difference of two cylinders.

- *Texturing:* Texturing is a term that refers to graphical or visual representation of of the material properties of the surfaces of 3D shapes [7, 8]. These material properties include the diffuse and specular color of the surface (For example, gold has both diffuse and specular colors of yellow. On the other hand a red apple has a red diffuse color and a white specular color), diffuse or specular reflection properties (For example, plastics have mainly diffuse reflection, on the other hand, shiny metals have a strong specular reflection). All these properties do not stay the same over a real surface as years of wear and tear effects the surface properties. Dirt collection can also create a significant change to a surface. Therefore, it is generally important to describe these properties as textures that are mapped over the 3D surface. Example of texturing a sphere are shown in Figure 2. In this figure, (A) shows a sphere without a texture and (B) shows two examples of texturing a sphere. For compressor animation, texturing is particularly useful to correctly visualize the rotation of rotation symmetric parts such as spheres or cylinders.

- *3D Animation:* This refers to the definition of the motion of the modeled shapes in

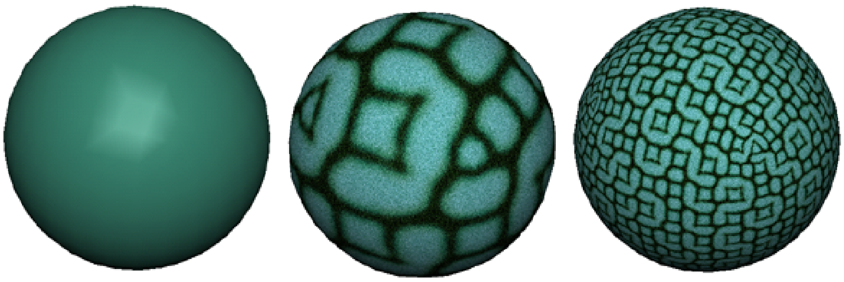


Figure 2: Examples of texture mapping.

3D space [7, 8]. Fortunately, almost all the objects in the ASHRAE Handbook are rigid bodies. Therefore, the animations to be created for ASHRAE handbook can be defined using translations and rotations (3 positions and 3 orientations that represent 6 degrees of freedom for the rigid body). In order to create animations, each moving rigid shape requires 6 curves, which are given as functions in time, by the animators. These functions are generally described using interpolation curves that can be changed by moving selected control positions. Since the parts of compressors repeatedly make the same motion, it is also important to determine the periodicity of the cycles in order to create animations. Another concern is to make cyclic animations smooth and continuous. To achieve smooth and continuous motion, each one of the 6 animation curves must begin and end with the same value and derivative.

- *Rendering, Lighting and Staging:* Rendering means to create images based on the given positions and orientations of camera, lights, shapes and textures [7, 8]. Lighting means to define the lights for creating better images. At least 3 lights, the key, fill and back lights, are needed to achieve a well-lit image. To improve the quality, there often is a need for additional lights. Staging is the choice of the camera position that yields the best view to display the visual information with the most clarity.

- *Compositing:* This is the step to combine the animations and images to create the final movie. The process may sometimes include combining real movie footage with computer graphics animation, adding titles and credits and adding special effects. The compositing stage is one of the key steps in current moviemaking practice.

- *Interactive 2D Computer Graphics:* This describes the user interaction with a 2D scene. Several formats such as Open-GL or JAVA can provide tools for interaction with a 2D scene. For this project, we use JAVA to provide an interactive environment on the web for interactive 2D charts.

- *Interactive 3D Computer Graphics:* This describes the user interaction with a 3D scene. Several formats such as Open-GL, JAVA 3D and VRML provide interaction with a 3D scene. For this project, VRML is particularly useful since it provides an interactive environment on the web without writing any additional code. Most animation packages provide tools to export a scene into the VRML format.

3 Scope of the Project

ASHRAE Research Project 1017-RP was meant to include a wide range of multimedia techniques and advanced visualization methods for presenting information, including: two and three dimensional animations of dynamic parts, audio clippings to accompany animations, 3D VRML models and animations, interactive 2D charts and diagrams, and the use of Computational Fluid Dynamics.

3.1 Two Dimensional Animations of Dynamic Parts (Parallel Projection)

For scroll, rolling piston and rotary vane compressors the most suitable staging of the compressor motion can be accomplished by parallel projection. For these compressors, Chapter 34 provided only static, two-dimensional figures to illustrate the method of operation. Unfortunately, these figures include many dynamic elements such as rotating and translating parts. It is extremely difficult to understand how these rotating and translating parts move together during the compression cycle by viewing static images alone. Therefore, the visualization of some compressors as 2D animations can be a useful tool. Although, the end results are 2D animations, we first developed high quality three-dimensional computer models using a commercial software package [12]. We then created 2D animations of rotating and translating parts using parallel projections of the 3D computer models. Parallel projection technique provides side, front or top views of a model [7, 8]. An example of parallel projections and a perpective projection is shown in Figure 3.

To improve the quality of the visualization of rolling piston and rotary vane compressors we used a 2D flow animation method developed earlier by Akleman et al. [13]. Rolling piston compressors use a roller mounted on the eccentric of a shaft with a single vane or blade suitably positioned in the non-rotating cylindrical housing. (generally called the cylinder block.) This blade reciprocates in the slot machined in the cylinder block. This reciprocating motion is caused by the eccentricity of the moving roller directly below the blade that repeatedly lifts the blade. In order to create a rolling piston animation, we developed a simple texture-mapped 3D model for the compressor and animated the cylinders. We then rendered this animation using a parallel projection technique. The flow animation, which is used to give the illusion of the gas flow in the compression was created separately. These two animations were then combined using a compositing program [15]. Selected frames of the resulting animation are shown in Figure 4.

The rotary vane compressor that was animated is an eight-bladed compressor. The eight blades in the compressor create eight discrete volumes or cells. In this compressor, a single shaft rotation produces eight distinct compression strokes. In a similar fashion as the

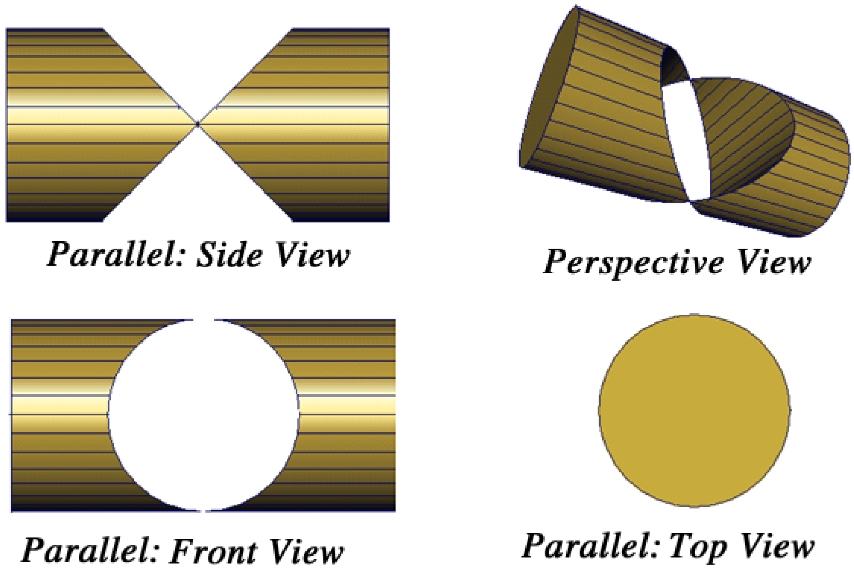


Figure 3: An example of parallel projections and a perspective projection. The shape used here is a set difference of two cylinders that is shown in Figure 1.D

rolling piston animation, the rotary vane compressor is modeled, animated and rendered in 3D using a commercial software package [12]. Likewise, flow animations were also created separately using the method by Akleman et al. [13]. Then these two animations were combined by using a commercial compositing package [15]. Selected frames of the resulting animation are shown in Figure 5.

Two-dimensional animations of dynamic elements in section views were implemented in the widely available Quicktime format [4]. Widely distributed public domain movie ”viewers” can be used to view these animations.

3.2 Three Dimensional Animations of Dynamic Parts (Perspective Projection)

Due to their complex motions, the working principles of single-screw, twin-screw and centrifugal compressors need to be visualized with 3D perspective projection. Currently, the Chapter 34 figures related to these compressors were drawn using static perspective projection, to show rotating and translating parts. Unfortunately, these static images provide little insight about how these these parts move during the compression process. Therefore, to better understand the working principles of such compressors animations were created using 3D perspective projection.

To represent these compressors, we first developed high quality three-dimensional computer models using a commercial software package [12]. We then produced animations showing the dynamic operation of these compressors and the compressor components using photo-realisticly rendered animation images. An example of photo-realisticly rendered 3D animation image frame is shown in Figure 6. These 3D image frames provide ”picture-quality” solid-looking dynamic representations of the critical components of each type of compressors. The animation then shows the dynamic operations of the components.

Unfortunately, in this case, we could not use the earlier flow animation method [13] since it can only produce a 2D flow animation. Instead to represent the approximate path of the fluid flow, we used 3D arrows and ellipsoids. Visualized 3D fluid flow characteristics were validated by observing actual compressor operation. These three-dimensional animations were created in one of the popular viewing formats [4]. Movie ”viewers” for these files are included as as an integrated part of the 1017-RP Demonstration CD-ROM.

3.3 Three Dimensional VRML Models for Viewing Dynamic Parts

For twin-screw and centrifugal compressors, perspective projected animations can provide a way of viewing the dynamic operation of these complex compressors. However, a deeper understanding can be provided if the viewer can interact with the animation (i.e., rotate or translate the 3D animation). Therefore, to provide interactivity for users, compressor animations were implemented as interactive three-dimensional models and animations described using Virtual Reality Modeling Language (VRML) animations [6]. Using an interactive public domain VRML viewer, the user’s three-dimensional viewing position and orientation, can be interactively modified to allow dynamic views from any viewpoint. VRML animation can even allow the viewer to go inside the animated three-dimensional model. The quality of VRML-based animation is limited by the detail of the 3D model and graphic capability of the user’s computer. In order to demonstrate VRML animation, interactive VRML animations for rolling piston, rotary vane, twin-screw and centrifugal compressors were developed.

3.4 Audio for the Animations

To identify certain problems during compressor operations, engineers often need to hear the sound the compressor creates during the compression cycle. To satisfy this need, real audio tracks for a centrifugal compressor were provided by one of the PMCS members, who works for a large chiller manufacturer, and integrated into the new electronic chapter using a simple HTML link to the sound file. These sound tracks include actual sounds from real compressors under various operating conditions recorded at the manufacturer’s laboratory. They can be heard with any one of the several widely available digital audio players.

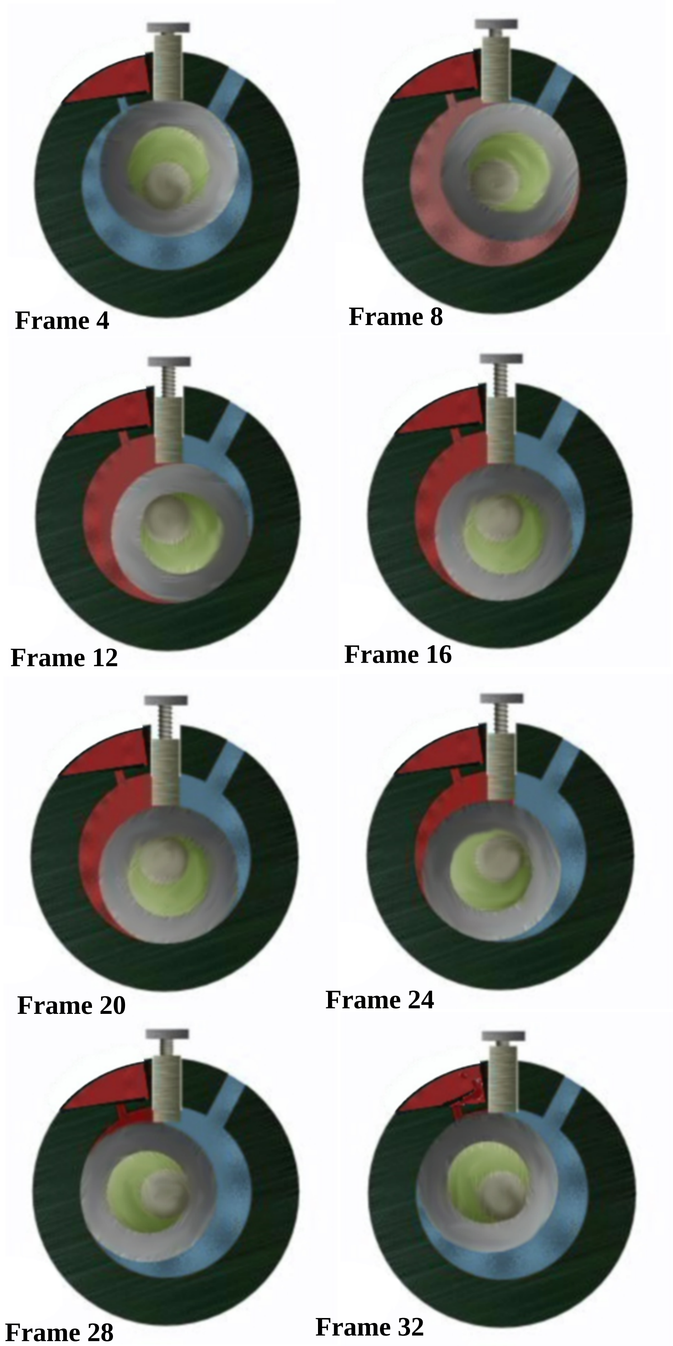


Figure 4: Selected (every 4th) frames of a rolling piston animation. The numbers below indicate the frame number. The whole animation consist of 32 frames. Note that the piston rolls clockwise.

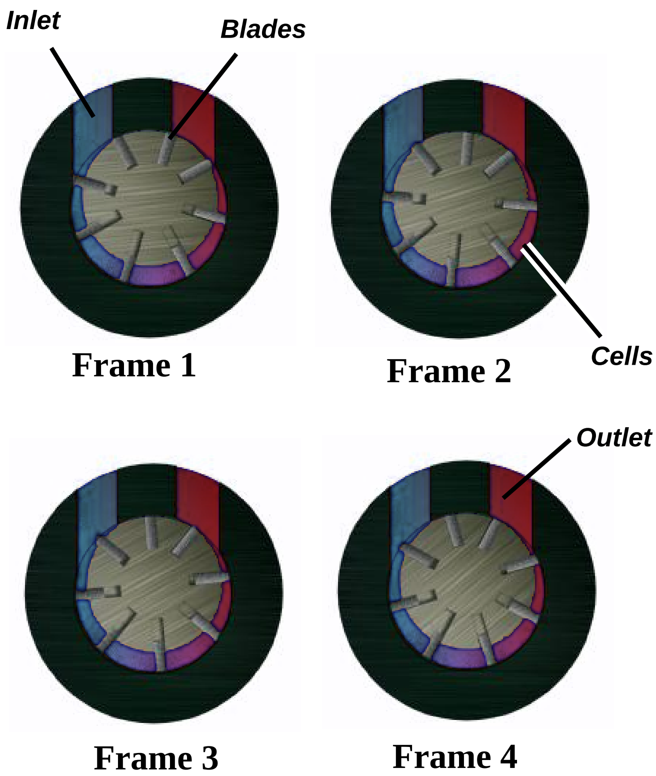


Figure 5: The four consequitive frames of a rotary vane animation. The numbers below indicate the frame number. The whole animation consist of 32 frames. Note that the vane rotates counter clockwise.

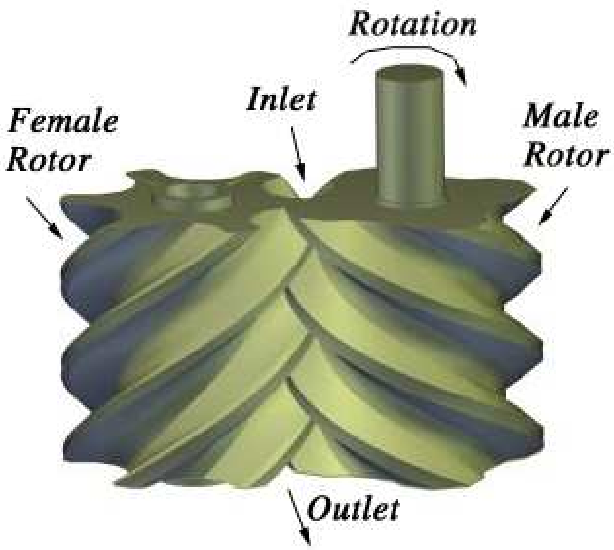


Figure 6: A Frame From the Twin Screw Animation.

3.5 Interactive Two Dimensional Charts and Diagrams

Performance charts can also benefit from interactivity, where the Handbook user could interactively manipulate the independent variable values and view how the resulting operation impacts the compressor operation. These interactive two-dimensional charts and diagrams were developed using the JAVA platform-independent programming language [5].

One example of the usage of such an interactive chart is a compressor performance map with superimposed system characteristics shown in Figures 7 and 8. To accomplish this we developed a JAVA program to provide interaction with this chart. The program lets the user change the inlet guide vane angles and view how this affects the compressor operation.

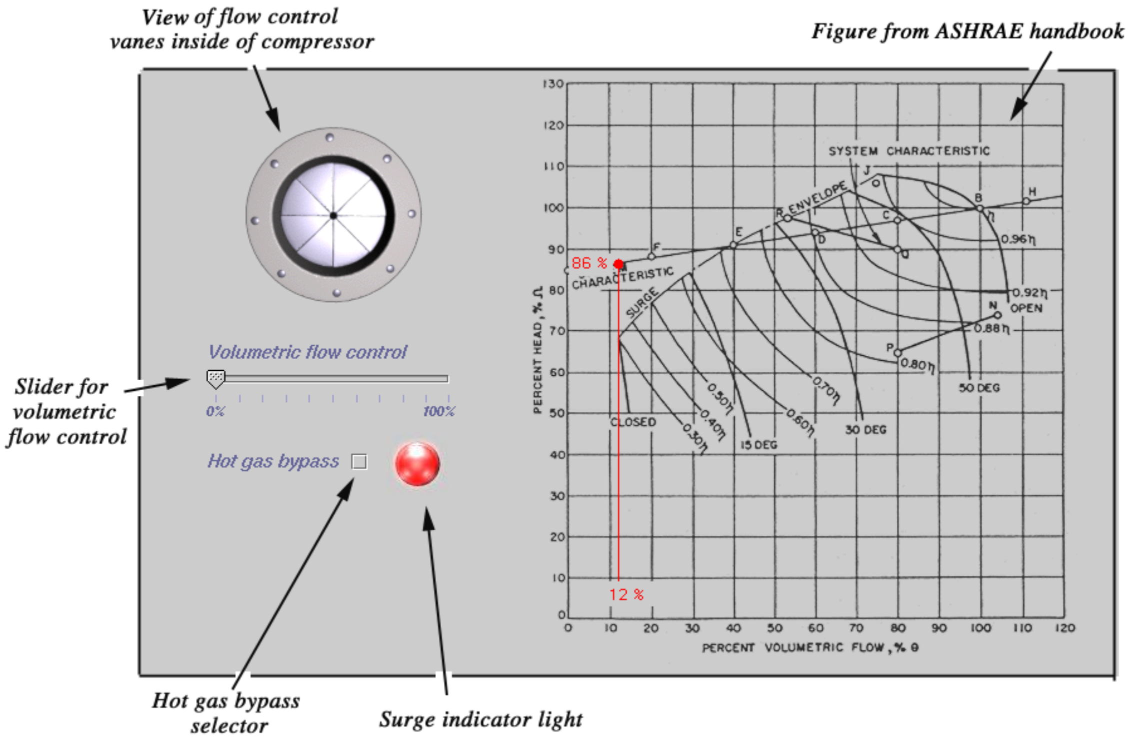
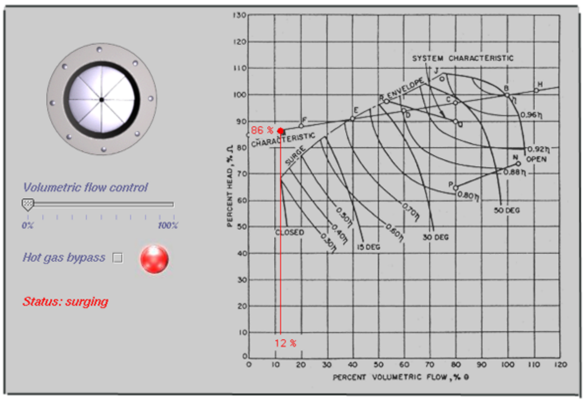


Figure 7: The actual interface of the interactive JAVA program that lets the user interact with a compressor performance map.

Another JAVA-enabled example was developed to show the relationship between different state points on a refrigeration cycle and the corresponding values on the enthalpy-pressure charts. In this JAVA program, the user selects a particular state point on the system diagram and views the corresponding values shown on the enthalpy-pressure diagram. The user interface of this program is shown in Figure 9.



A) Status: Surging. Surging light is red. Hot gas bypass is off.

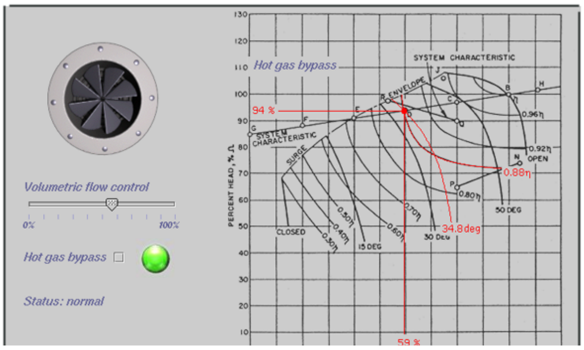
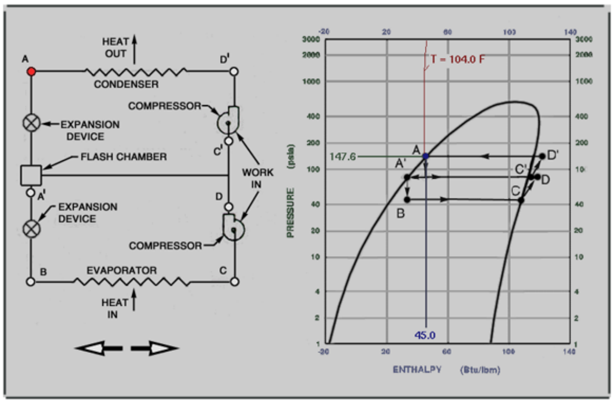


Figure 8: Three views of interactive JAVA program interface that show three different states of compressor operation.



A. Conditions of the cycle prior to first expansion device

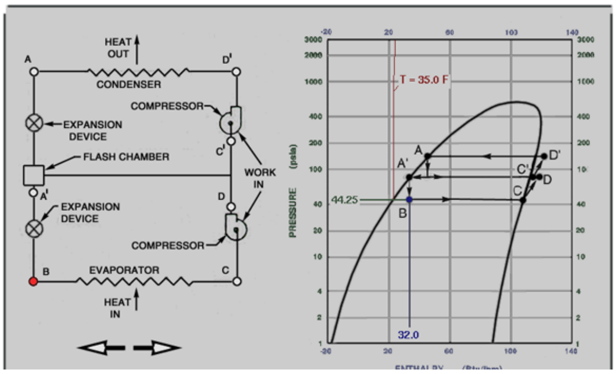


Figure 9: Three views of of the JAVA program interface that allows the user to interact with a refrigeration cycle and view its corresponding values on the enthalpy-pressure diagram.

3.6 CFD

To understand how compressors work, it may also be helpful to have detailed animations of the gaseous refrigerant as it passes through the compressor. Unfortunately, compiling and assembling new images was beyond the scope of this research project. Therefore, to provide a suitable demonstration of these animations, we reformatted previously developed computational fluid dynamics (CFD) animations of a Wankel combustion engine performed by Thornton and Andrews [16].

One of the animations we provided shows the grid layout for a 3D simulation of a moving Wankel engine. This animation at the grid layout helps one to understand how the complex wankel combustion chamber is subdivided in order to analyze the combustion process.

Another animation shows the computer simulated fuel sprays as they enter the combustion chamber, travel into the combustion cup and are ignited. The different colors indicate sprays from 6 different nozzles. Initially the pilot spray may be seen, quickly followed by the main sprays. Ignition of the pilot fuel spray spreads to the main sprays, and spray drops can be seen combusting (i.e. changing color and reducing in size).

The third animation we provided shows a slice through the combustion chamber from leading to trailing edge and includes the combustion cup as shown in Figure 10. The colored contours in this animation correspond to temperature and mass fraction. Thus, early in the movie as the sprays are injected drops evaporate and the mass fraction is seen to increase. At ignition the temperature field turns red (high temperature) and fuel (mass) is fed the flame (high/low temperature interface). At a later time all the fuel is burnt and the temperature cools as the hot gases are exhausted.

4 Conclusions and Future Work

ASHRAE Research Project 1017-RP has demonstrated the effectiveness of multimedia and advanced presentation techniques for ASHRAE Handbook. This demonstration can serve as a model and guide for the broader use of these techniques in other ASHRAE publications. ASHRAE already published a copy of the 1017-RP final report CDROM, which includes a multimedia version of Chapter 34. This CD-ROM version of the enhanced chapter is already available from ASHRAE.

One of the major goals for the future is that the *cost effective* conversion of the remaining chapters of the ASHRAE handbook into a similar multimedia representation. This goal can be accomplish by providing ASHRAE TC Handbook committee members with the tools and the knowledge they will need to create multimedia images. We are currently writing a detailed paper on 3D modeling and animations of compressors [17].

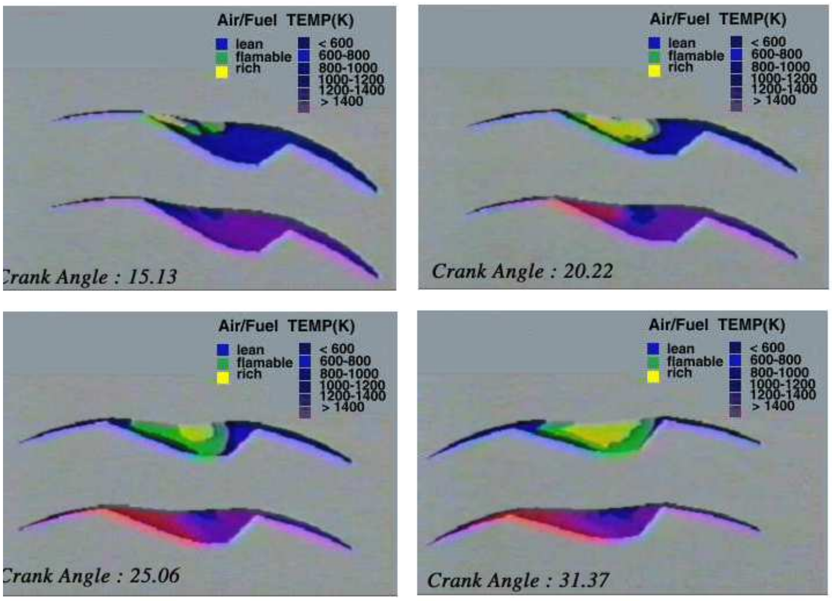


Figure 10: Example frames from one of the CFD animations.

5 Acknowledgments

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