Demonstration of Multimedia Electronic Information Enhancements for a Handbook Chapter CD-ROM: Overview

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ABSTRACT

A set of enhancements to the ASHRAE Handbook are presented to demonstrate the effectiveness of multimedia and advanced presentation techniques, such as three-dimensional 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.

GENERAL INTRODUCTION TO PROJECT

In this paper, we present a set of enhancements to the ASHRAE Handbook that demonstrate the effectiveness of multimedia and advanced presentation techniques, such as three-dimensional 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 (ASHRAE 1996).

Chapter 34 covers various types of compressors, such as centrifugal, scroll, rolling piston, and twin-screw, 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 two-dimensional 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 the 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 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, nonproprietary, 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 (Miano 1999) or JPEG images (Pennebaker and Mitchell 1992; Miano 1999), two-dimensional and three-dimensional Quicktime animations (Gulie 2000), interactive JAVA applets (Sun 2001), or as three-dimensional VRML models (Pesce 1997).

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 Carlson (2001).

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) (Miano 1999) and Joint Picture Expert Group (JPEG) (Pennebaker and Mitchell 1992; Miano 1999) 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 three-dimensional 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 [Hoffman 1989; Mantyla 1988]) over primitive shapes. An example of set operations is shown in Figure 1 for two separate cylinders (Figure 1A), the union of two cylinders (1B), the intersection of common volumes of both cylinders (1C), and the set difference (1D). 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.

- **Texturing:** Texturing is a term that refers to graphical or visual representation of the material properties of the surfaces of three-dimensional shapes (Foley et al. 1995; Watt and Watt 1992). 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) and 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 affect 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 three-dimensional 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.

- **Three-Dimensional Animation:** This refers to the definition of the motion of the modeled shapes in three-dimensional space (Foley et al. 1995; Watt and Watt 1992). Fortunately, almost all the objects in the ASHRAE Handbook are rigid bodies. Therefore, the animations to be created for the ASHRAE Handbook can be defined using translations and rotations (three positions and three orientations that represent six degrees of freedom for the rigid body). In order to create animations, each moving rigid shape requires six 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 continu-

![Figure 1 An example of set operations: union, intersection, and set difference of two cylinders.](image1)

![Figure 2 Example of texture mapping.](image2)
uous motion, each one of the six 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 (Foley et al. 1995; Watt and Watt 1992). Lighting means to define the lights for creating better images. At least three 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 Two-Dimensional Computer Graphics:** This describes the user interaction with a two-dimensional scene. Several formats such as Open-GL or JAVA can provide tools for interaction with a two-dimensional scene. For this project, we use JAVA to provide an interactive environment on the web for interactive two-dimensional charts.

- **Interactive Three-Dimensional Computer Graphics:** This describes the user interaction with a three-dimensional scene. Several formats such as Open-GL, JAVA 3D, and VRML provide interaction with a three-dimensional 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.

**SCOPE OF THE PROJECT**

ASHRAE Research Project 1017 was meant to include a wide range of multimedia techniques and advanced visualization methods for presenting information. These methods include two- and three-dimensional animations of dynamic parts, audio clippings to accompany animations, three-dimensional VRML models and animations, interactive two-dimensional charts and diagrams, and the use of computational fluid dynamics.

**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 two-dimensional animations can be a useful tool. Although the end results are two-dimensional animations, we first developed high quality three-dimensional computer models using a commercial software package (Boardman 2001). We then created two-dimensional animations of rotating and translating parts using parallel projections of the three-dimensional computer models. Parallel projection technique provides side, front, or top views of a model (Foley et al. 1995; Watt and Watt 1992). An example of parallel projections and a perspective projection is shown in Figure 3.

To improve the quality of the visualization of rolling piston and rotary vane compressors, we used a two-dimensional flow animation method developed earlier by Akleman et al. (2000, 2001). Rolling piston compressors use a roller mounted on the eccentric of a shaft with a single vane or blade suitably positioned in the nonrotating 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 three-dimensional 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 (Brinkman 1999). 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 fashion similar to the rolling piston animation, the rotary vane compressor is modeled, animated, and rendered in three-dimensions using a commercial software package (Boardman...
Due to their complex motions, the working principles of single-screw, twin-screw, and centrifugal compressors need to be visualized with three-dimensional perspective projection. Currently, the Chapter 34 figures related to these compressors were drawn, using static perspective projection, to show rotat­ ing and translating parts. Unfortunately, these static images provide little insight about how these parts move during the compression process. Therefore, to better understand the working principles of such compressors, animations were created using three-dimensional perspective projection.

To represent these compressors, we first developed high-quality three-dimensional computer models using a commercial software package (Boardman 2001). We then produced animations showing the dynamic operation of these compressors and the compressor components using photo-realistically rendered animation images. An example of photo-realistically rendered three-dimensional animation image frame is shown in Figure 6. These three-dimensional image frames provide "picture-quality" solid-looking dynamic representations of the critical components of each type of compressor. The
animation then shows the dynamic operations of the components.

Unfortunately, in this case, we could not use the earlier flow animation method (Akleman et al. 2000) since it can only produce a two-dimensional flow animation. Instead, to represent the approximate path of the fluid flow, we used three-dimensional arrows and ellipsoids. Visualized three-dimensional fluid flow characteristics were validated by observing actual compressor operation. These three-dimensional animations were created in one of the popular viewing formats (Gulie 2000). Movie “viewers” for these files are included as an integrated part of the 1017-RP Demonstration CD-ROM.

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 three-dimensional 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 (Pesce 1997). 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 three-dimensional 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.

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.

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

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**Figure 6** A frame from the twin-screw animation.

**Figure 7** The actual interface of the interactive JAVA program that lets the user interact with a compressor performance map.
the JAVA platform-independent programming language (JavaRef).

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.

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.
Computational Fluid Dynamics (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 (1993).

One of the animations we provided shows the grid layout for a three-dimensional 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 six 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.

CONCLUSIONS AND FUTURE WORK

ASHRAE Research Project 1017 has demonstrated the effectiveness of multimedia and advanced presentation techniques for the ASHRAE Handbook. This demonstration can serve as a model and guide for the broader use of these techniques in other ASHRAE publications.

One of the major goals for the future is 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 three-dimensional modeling and animations of compressors (Akleman 2003).

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