Chapter 16

PROJECTION USING CONVENTIONAL OPTICAL SYSTEMS

When we project a movie or slides, we make every effort to make the conditions ideal: We darken the room, provide a special screen with a surface designed to distribute the reflected light evenly to the entire audience, and we arrange for the projector to be directly on the centerline of the screen in such a way that the slide and screen are exactly parallel. These ideal conditions can seldom be met when using projection on stage. Instead, the screen is apt to be minimally reflective material and the projector and slide will be located somewhere at an odd angle to the screen. Worst of all, the stage will by brightly lit with an array of spotlights, many of which may spill light onto the projection surface. Under these conditions there are only two methods available for making projections on stage functional:

1. *High light output*: This requires special high-efficiency lamps, efficient light collection, fast lens systems and low-density image material which transmits as much of the light to the “screen” as possible. All of these are expensive.
2. *Readjust the stage lighting levels and angles to favor the projections*: This will require careful planning and often compromises the blocking of the actors. The lower the power of the available projection equipment, the more severe the compromises will have to be.

Considerations in Adopting Projection

The decision to use projection must come early in the production planning process. The pros and cons of its use should be clear to all members of the production team from the beginning. As noted in Chapter 15, the artistic advantages of properly used projection can be impressive. Contrariwise, an ill-advised decision to use projections, perhaps to avoid the effort and cost of building settings or to avoid difficult painting techniques can turn out to be a trap. The goal will probably not be reached and the production will be seriously damaged by the lost time, effort and funds squandered on projections that do not work.

Time and monetary savings are elusive.

The following techniques offer practical and artistic solutions to design problems and can, on occasion, even solve problems in a way that saves time and funds. However no production company should count on these savings actually accruing until they have a reserve of experience using projections and know their equipment and their theatre well enough to realistically predict what will happen when projections are used.

Multiple projectors can make the job easier.

Perhaps the first step in understanding the use of projections is to divest oneself of the notion of a "screen." This opens up the artist's thoughts to many challenging and creative alternatives as projection surfaces. The second step is to avoid the "classroom" or "movie theatre" notion of only one or two projectors doing the job—onstage projection may use numerous projectors located in a number of places backstage. This approach can have many advantages:

1. Large areas can be covered with images that could not be handled by a single projector short of a hugely expensive and massive device.
2. Brightness levels of the projection can be high because only a limited area is being illuminated by any individual projector.
3. Multiple projectors make it possible to change parts of the projected image without changing the whole. This opens vast artistic possibilities to the designer.
4. Multiple projectors make it possible for individual projectors to be oriented towards the surface they are designed to cover much more precisely than if one huge and powerful projector had to cover all of the surfaces on the setting. This makes control over distortion much simpler and increases artistic variability.

Square law ("Linnebach") projectors

The simplest of all projection techniques, shadow projection using a small ("point") light source and opaque materials, is an ancient Oriental art form which was reinvented for the theatre in the 19th century by August Linnebach, a German theatre designer and technician. Some Linnebach projectors (also termed square law projectors or direct beam projectors), mostly homemade, are still used today. Linnebach projectors produce very large but often soft, rather dim images at short throw distances. They can be the lowest priced projectors available, but in most situations, one of the modern array of lens projectors, ranging from reasonably priced units upward, will be a better choice.

Lens Projection

All slide and motion picture projectors, ellipsoidal reflector spotlights, and sophisticated automated luminaires work in basically the same way. In modern projectors, a lens, usually much more optically refined than that in an ERS, is used to form an image of a "slide" placed in the strongly illuminated aperture. The source of illumination is a high-powered T-H lamp or, more likely, an HID lamp. Its light is gathered and passed through the aperture in such a way that it converges on the entrance element of the projection

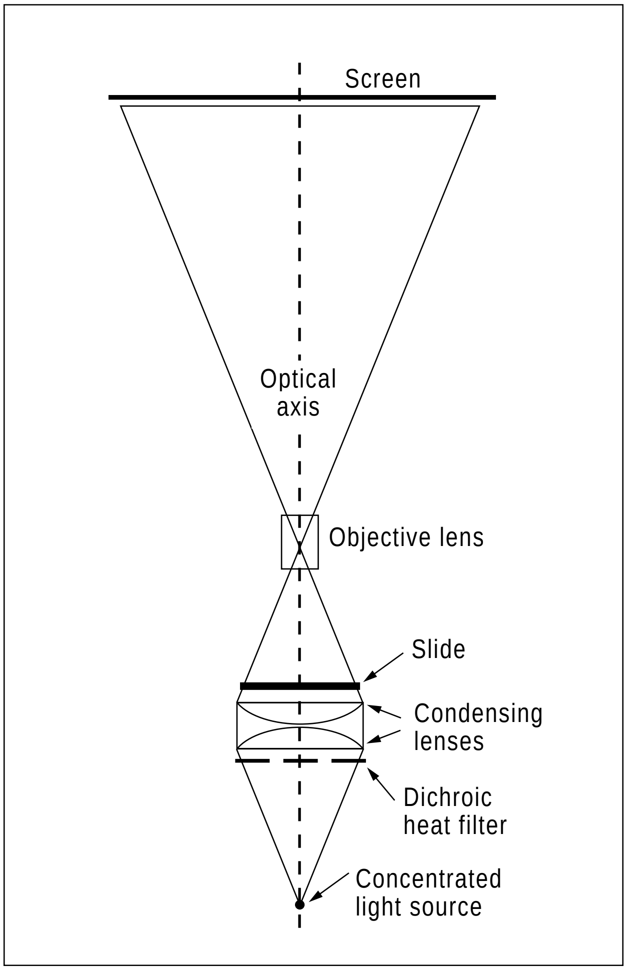

Figure 16.1. Lens Projection. This schematic drawing shows the essential elements arranged on the optical axis. Actual projectors may be more complicated but the principle of gathering the light from the source, passing it through the slide to the objective lens which forms the image on the screen applies to all lens projectors.

lens (Figure 16.1). The slide can be anything from the conventional glass plate with a photographic image bonded to it to a complicated arrangement of moving elements designed to create images of flames, rain or any other effect the designer can devise. The size of the projected image depends on the slide size, the focal length of the projection lens and the distance to the projection surface. Efficiency depends on the light source, the light gathering system, the density and size of the slide and the "speed" (i.e., the efficiency) of the lens. Sharpness of the image depends mainly on the optical quality of the lens.

Theatrical lens projectors have evolved from custom-made units often made in-house by an optical specialist, to modern commercially manufactured units, some of which are masterpieces of the optical engineer's work but very expensive and bulky (Figures 16.2A and 16.2B).

Spotlights as projectors

Modern luminaires such as ellipsoidal reflector spotlights and automated luminaires are basically projectors. Ellipsoidal reflector spotlights can be fitted with gobos to produce simple images which can cover about the same area as the pool of light normally produced by the luminaire. Similarly, automated luminaires can be fitted with slides and will produce high quality images covering about the same area as the luminaire would otherwise illuminate. With the exception of situ-

Figure 16.2A. Top-of-the-Line Scenic Projectors. These very expensive and massive machines represent the finest of the projector engineers' work. While usually too expensive for most theatres to own, they can be rented. Rental also usually includes the services of the rental agency's technical staff who can assist in the complicated job of setting up the machine(s) and preparing the image material. Photo courtesy Hardware Xenon, Inc.

ations where exceedingly powerful projections are needed, automated luminaires are rapidly monopolizing the field of scenic projection wherever they are affordable. (See Figure 16.4B.)

The Optical System

The optical axis

All parts of a good projection system are centered on its *optical axis*. This is a line through the center of each optical element and, ideally, extending to the center of the screen (Figure 16.1). Not only should all parts be centered on the optical axis, their optical planes should also be at right angles to it. Under these conditions, there will be no distortion due to misalignment, but optical distortion from lens or reflector faults may still exist.

The lamp house

The lamp house is the enclosure around the light gathering apparatus that contains spill light from the lamp and supports the lamp and its electrical leads. It may also carry the aperture apparatus and the objective lens. A lamp house is much like the housing of a high-powered spotlight; it must withstand heat, contain dangerous radiation, withstand occasional rough handling, and may have to be engineered to contain the violent explosion of a high-pressure lamp. In the case of theatrical projectors, it often fitted with mounting equipment such as a yoke and "C" clamp or a base that allows accurate tilting and panning.

Lamp house must withstand lamp explosion.

Collecting the light

The principle of collecting light in a projector is the same as that discussed in Chapter 7 in connection with the design of spotlights. However

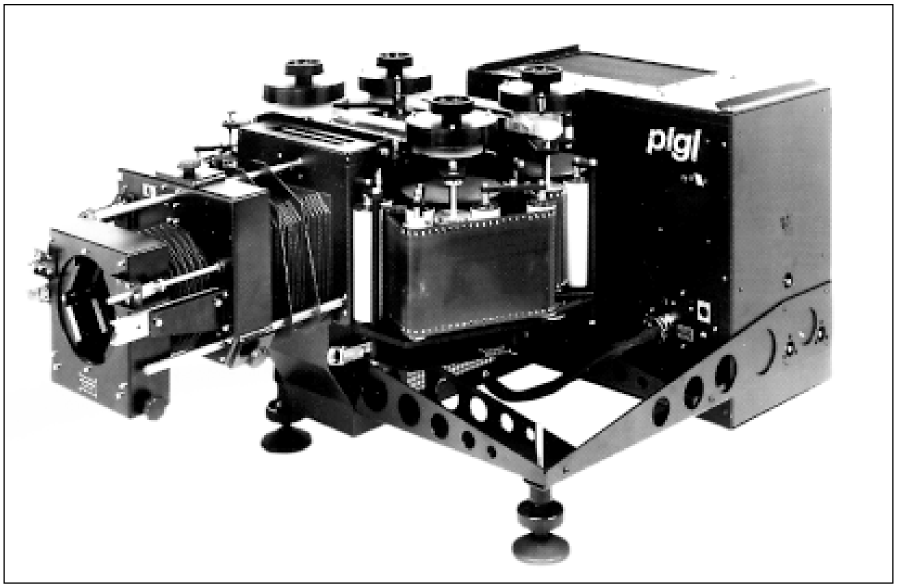

Figure 16.2B. Pigi Projector. This machine combines a powerful lens projector with a sophisticated “moving strip” image apparatus that can move two strips of images accurately in relation to each other. Movement can be in unison, in opposite directions or a still image with a moving one superimposed. The entire lens mount and aperture apparatus rotates via a motor drive making rotating images also possible. Image format is 155 mm x 155 mm.

The light source is either a 4kW or 7kW xenon lamp. Control is remote, including focus, speed and direction of image strip movement, intensity (via mechanical dimming), and rotation. All parameters are controlled by a computer which is compatible with EBU, SMPTE and MIDI protocols. Courtesy Fourth Phase (Production Arts Lighting).

collecting light for projection is more demanding. The object of the system is to gather as much of the light output of the lamp as possible and direct it through the slide and into the rear element of the objective lens. In general, two approaches are to be found:

1. A conventional spherical mirror, plano-convex lens arrangement upgraded by the use of the best quality mirror and one or more high-quality lenses designed to converge the cone of light to a diameter equal to the diagonal of the slide. Furthermore an additional lens, sometimes called a “collector,” may be installed just in front of the slide to converge the light passing through the slide into the rear element of the objective lens.
2. Adaptations of the ellipsoidal reflector system may be more efficient overall than the lens system above. These gather and direct the light with greater efficiency than the lens train method. These special mirrors can also be made of dichroic material (see Handling Heat below).

Handling heat

Any incandescent source powerful enough to be useful in scenic projection will produce a large amount of heat, part of it as heated air and the rest as infrared (IR) light. The heated air must be exhausted either by convection or forced ventilation. The infrared is picked up by the collection system and passed along to the slide unless special precautions are taken. A “low tech” solution to this problem is to install a heat filter of IR block-

Dichroic mirrors can filter out IR.

ing glass in the optical chain just before the slide. This filter will absorb the IR, converting it to heat which must be removed by air circulation. A better solution is to install a cold mirror (dichroic filter) at the above position. This will pass the visible light and reflect the IR back toward the source (see Figure 16.3). In addition, using a hot mirror (also a dichroic filter) as the light collecting mirror (spherical, ellipsoidal or special geometry) will pass the IR through the back of the lamp house and reflect the visible light toward the lens. If these measures are not sufficient, or if they prove too costly, the slide may have to be cooled by a blast of air from a special fan. This will make additional noise and require extra electrical circuitry.

Although HID sources are much more efficient than incandescent, they may still produce enough heat as IR to require the use of dichroic mirrors and filters.

Image Material

Slide shows both on- and off-stage date well back into the nineteenth century. These used painted slides first and later photographs. Moving stage effects such as rain, clouds and fire produced by rotating disks moving through the aperture have an equally long history. Modern moving effects include a wide variety of moving gobos and strips of film accurately controlled and highly sophisticated in their quality of images. (See the Pigi and other projectors in Figure 16.2.) Furthermore, projection specialists even today may devise apparatus as needed for specific shows. In any case, this image material must be accurately placed on the optical axis, carefully located within the depth-of-focus region of the lens and fully illuminated.

Low density photographic slides preferred

Whatever the image material, it must be capable of resisting the effects of the heat in the beam and, if it is a photographic or painted slide, resisting the fading action of the light. With the exception of silhouette-type slides intended to produce shadow images, the lower the density of the image the better. A photographic color slide developed for the lightest density possible while still retaining the image quality needed, can often add more to the brightness of the image than any other single element in the entire optical system.

Objective Lens

The ideal objective lens

The objective lens is the most important part of the optical system. Ideally it should transmit a high percentage of the light striking its rear element, focus every part of a large slide sharply and evenly and distribute the image over the screen without hot spots or dark areas. It should do all of this at very short throw distances and be highly resistant to the effects of high heat from the light beam. Finally, it should be light in weight, small in size, and economical to purchase. Such a lens does not exist.

The objective lens, or better, a set of objective lenses, will usually be one of the most expensive parts of the theatre's projection system. The best lenses are specially made for this service and come as close to the ideal as cost and optical skill will allow. One major difficulty is the optical fact that the shorter the focal length of the lens, the more difficult it is to make it meet the other theatrical requirements. Thus the lenses most needed—those for short throws—are the very lenses that are hardest to make and are therefore the most costly.

Objective lenses are described by their focal length stated in inches or millimeters and their speed (the efficiency with which they handle light) stated as an "*f*" number (e.g., 4.5 inches, f=3.0). Objective lenses may come as part of a system or be purchased separately. Since the outside diameter of objective lenses varies considerably from lens to lens, the projector must be equipped to allow the secure but adjustable mounting of each lens. Worse, projectors designed for a particular set of lenses are not likely to accept lenses of another make without devising special adapters.

Note that camera lenses will not serve as projection lenses for high-powered projectors even though they may have the proper speed and focal length. They cannot handle the heat load and will be destroyed.

Audiovisual Projectors on Stage

There are two types of standard audiovisual equipment that are adaptable to the stage, although with limitations. These are the 35mm slide projector and the overhead projector. In an academic situation these can sometimes be borrowed from the audiovisual department, although it will be far better for the theatre to own this equipment. The wrath of an A-V department receiving its much-abused projector back complete with paint and dye spatters and evidence of overheating is not pleasant to contemplate.

35mm Audiovisual Projectors

Classroom projectors on stage

If the stage is small and the projected image need be no larger than the usual slide image for classroom projection, a standard Carousel or similar projector may be used. Standard lenses are usually available down to about a three inch focal length and zoom lenses are common. The three-inch lens or a zoom set to its shortest focal length will produce theatrically useful image sizes at backstage throws. Since these projectors are not designed to hold the same slide on the screen for long periods of time, care must be taken to limit the continuous "on" time and to allow time for cooling between uses. Otherwise slides may be destroyed and projector parts overheated. Also, these classroom projectors will not take kindly to dimming unless they are rewired to remove the fan from the lamp circuit which may then be dimmed.

Powerful 35 mm projectors

Specially adapted 35mm projectors are also available. These have improved light gathering systems, much more powerful lamps, some including xenon, and are equipped with special cooling blowers wired separately from the lamp circuit. They can also be fitted with special, faster projection lenses capable of handling high heat loads. Note that regular slide projector lenses may not survive in these high-powered projectors.

Overhead Projectors

Overhead projectors are commonly used in situations where the lecturer wants to use overlays to build up an image as the lecture progresses. The image material, usually printed on clear acetate stock, is placed on a glass plate which forms the top of the lamp house. The light collection system directs the light to cover the entire glass top and then converges it into the rear element of the objective lens which is mounted on a post extending over the slide. The lens includes a prism which redirects the light toward the screen.

The open slide area of these projectors makes them useful for all manner of projection devices including some which can provide movement of the image. For example a shallow dish holding colored oil and water can be gently moved or rhythmically tapped to form a constantly varying pattern. This is the principle of the "psychedelic" images common in night clubs of the sixties. Unfortunately the same open construction makes these projectors produce lots of spill light. Attempts to dim these units may cause the fan motor to overheat if it is not separated from the lamp circuit.

Dealing with Distorted Images

Distortion may be controlled to artistic advantage.

Distortion is not always a negative factor. In many cases, such as projecting clouds, it can be an advantage. Likewise in the projection of abstract forms for, say, an expressionistic production, distortion can become a major element of the design. The key is control. The artist must be in control of the distortion and be able to adjust it to his or her wishes. With experience, designers will learn to control distortion by choice and adjustment of lenses, placement of the projector(s), the location and nature of the projection surface, and by the manipulations discussed below.

Although there are many sources of distortion, the most common one on stage is caused by the fact that the slide and the projection surface are not parallel to each other. If the slide cannot be made parallel to the screen, here are some other methods of controlling this type of distortion:

Preparing a distortion correcting grid

1. Develop a distortion grid to be followed as the slide is being painted. (See Figure 16.3.) This method is used by professional projection artists who paint their own slides. It can be a very exact method. Many theatres, particularly European opera houses maintain a complete set of distortion grids developed for various projector locations for projection onto their cyclorama. Note that if either the projector or the projection surface is moved, the grid will become inaccurate and a new one may be needed.

   One of the most accurate and efficient ways of developing a grid is to use a special drop gridded with horizontal and vertical lines every foot. This drop is hung at the plane of the intended projection and illuminated. A camera is placed at the projector location, its film plane parallel to that of the intended projector, and photos taken. Positive prints of these photos may be enlarged or reduced to fit the size of the slides to be painted and used to guide the artist in that painting.

2. Use photography to correct for distortion. The image is painted on a flat surface with the design shown as it is intended to appear on stage. It is then photographed by a camera placed at the same relative angle and position to the image material as the slide will be when used on stage. The lens makes the distortion corrections. This will work as long as the projection surface is essentially a plane.

   This method can be expensive because of the need for large-format color transparencies. Such transparencies must be as low in density (transmit as much light) as is feasible. This means that the theatre must either equip and operate its own color laboratory or must find a custom color lab that will understand what is needed and produce consistently useful slides. The slides should be ordered in multiples because they will be subject to bleaching

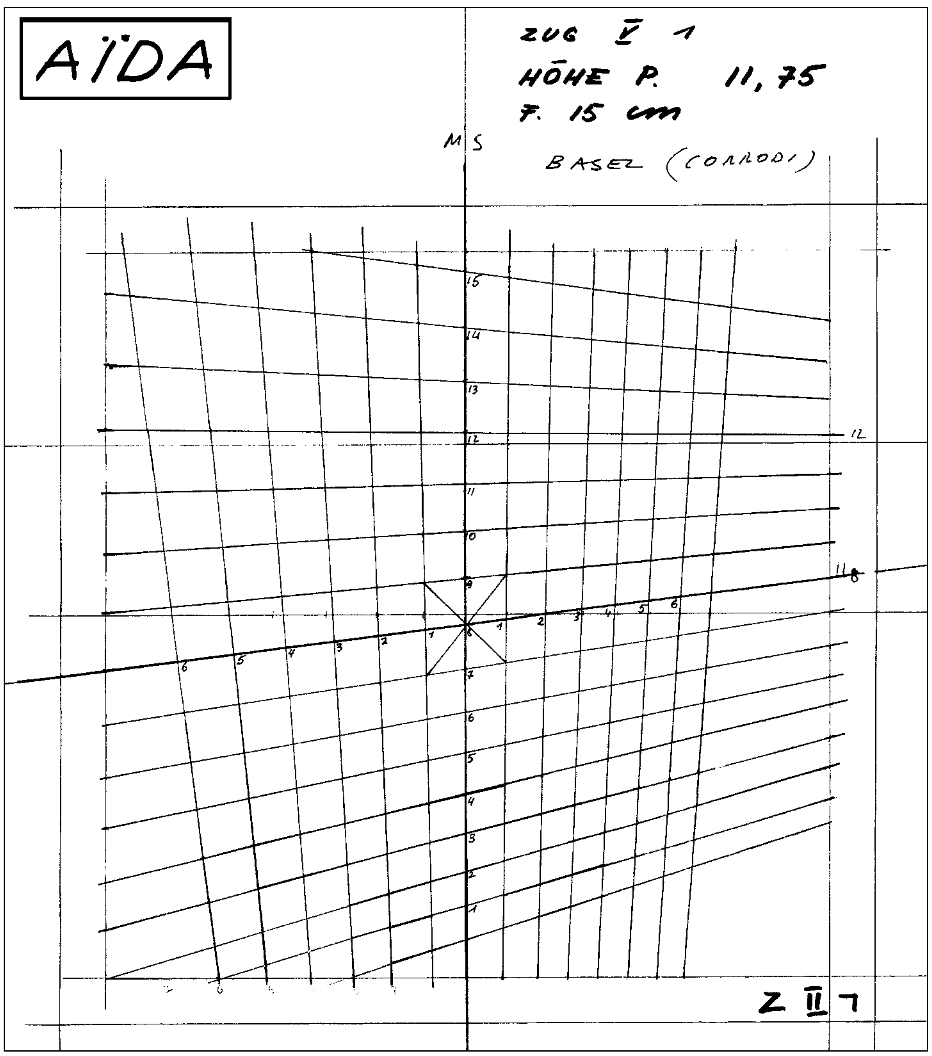

Figure 16.3. Distortion Grid. This grid is typical of those prepared by projection artists before sketching in the outlines of a painted slide. It is for a production of *Aida* designed by Annaliese Corrodi, scenographer, Basel, Switzerland. Note the line marked “M.” It defines the middle of the projected area and is one of the key orienting lines followed by the artist. Grids are prepared for specific projector “screen” locations and must be redone whenever either the projector or the projection surface change position.

and warpage from the effects of the light beam.

3. Use computer graphics techniques. This involves scanning the original art work or photographs into a computer with enough memory to handle the large files thus created, and manipulating the images to get the desired image, including distortion correction. Then the digital image is printed on color film to make up the projection slide. The 35mm format is economical for this process, although larger formats may produce sharper images.[1]

   This digital technique requires the use of sophisticated and expensive equipment such as high-quality scanners and film printers, plus skilled use of graphics programs such as Adobe Photoshop. If this equipment is available through an academic computer facility, it may be possible to use it with low cost. Another more expensive option is to use the facilities of a computer service bureau.

Front and Rear Projection

Stage projection may be done from either the front or the rear of the projection surface or even a combination of the two. Obviously rear projection (RP) requires surfaces that transmit light and, ideally, disperse it over an angle equal to the widest part of the house. A variety of commercially made RP screen materials is available in assorted "gains" and in both white and black screen types. The "gain" of a screen describes its ability to narrow the spread of the image and thereby increase its brightness to the observers within its effective angle. Gain is described by numbers beginning with 1 which describes a 100% diffusion screen that spreads the light evenly over 180°. Higher numbers describe screens that produce a brighter image but over a narrower viewing angle.

"Gain" of a projection screen

White screens are often slightly more efficient, i.e., they transmit more light, but they are also more apt to pick up spill light on the front which dilutes the image. However, they can also be used for front projection or simultaneous front and rear-projection. Black screens absorb spill light and thus increase the contrast and apparent brightness of a rear-projected image. Both white and black screens will evidence a "hot spot" or flare visible to members of the audience on a line from their point of view to the projector unless their dispersion is great enough to eliminate this effect. This degree of dispersion may make the screen too inefficient for some uses. Yet another way of avoiding "hot spots" is to place the projector so that no member of the audience is on a direct line-of-sight with it. This results in less efficient projection because no light passes through the screen directly toward the audience, but can produce evenly distributed brightness.

"Hot spot"

A variety of materials other than commercial projection screen material can be used for either front or rear projection. While these will not usually be as optically efficient as the commercial materials, they may blend into the setting much more effectively and can lead the designer

[1] See "Multi-Image Slides for Everyman" by Barrett Cleveland and David Guard, *Theatre Design & Technology*, vol. 33 no. 5 Fall 1997, p 28 ff, for details on this technique.

to create very unusual and artistically effective stagings. For example, Josef Svoboda, the well-known Czech scenographer, has used multiple layers of theatrical gauze dye-painted with abstract designs as a projection surface for front projections. Each gauze layer was spaced from those near it. The combination of the fixed (painted) images and the much-varied projected images was further enhanced by the fact that the projections were multiplied by passing through several layers of gauze before they became invisible. The projected images were seen as offset from one layer of gauze to the next because the projectors were directed towards the gauze drops at an angle. If the designer is sufficiently skilled at projection, specially designed parts of the projected images can be superimposed over

Projections on multilayered gauze

Figure 16.4A. Projection On Scenic Elements. *Tannhauser*, Venusberg scene. The setting is made up of irregular reflective elements large enough to tower above the actors standing in the openings. Scenography and photo by Josef Svoboda.

Figure 16.4B. “Droplet Gobo.” These images are produced by automated luminaires all equipped with the same gobo. Note how the shapes of the setting pieces vary the effect of the images projected. Courtesy High End.

specific parts of the painted image producing designed color changes.

Given a satisfactory RP screen, RP is more desirable for stage use if there is back stage space for the projector(s) at proper throw distance. This is because RP is usually more efficient than front projection and also because actors can play near the front of the RP screen without casting their shadows into the image. However it is still necessary to protect the image from spill light.

Settings As Projection Surfaces

In many cases the designer will plan to use parts of the setting as projection surfaces. (Figures 16.4A and 16.4B) Naturally, the more reflective these are, the better. Since most scene paints dry to diffuse surfaces, they are useful, but low in gain, if the pigments are light enough in color to reflect adequate light. The rules governing the effect of colored light on colored objects will prevail making the effect of the projection dependent on the color of the surface.

Fabrics, either as costumes or as parts of settings or as a sky drop or cyclorama, can also serve as projection surfaces if they are not dark and heavily absorbent. Dark velours, for example, are almost totally non-reflective. Obviously the shape of the set pieces or costumes will determine the way the audience sees the projections. This is a matter to be controlled by the designer who should be able to exercise total control over setting, lighting and costumes for this purpose.

Cycloramas and sky drops provide reasonably good projection surfaces, however age and soil tend to reduce their efficiency. Cycs, in particular, present a problem in both coverage and distortion control. The sheer size of the cyclorama and limits on backstage space almost always rule out rear projection. Front projection will be the only choice and it must deal with the "U" shape of the cyc. This is not a problem for projection of clouds or completely abstract images but rectilinear images will be severely distorted. The grid and photographic methods for correction can be effective but a special problem will be encountered: Covering a full-stage cyclorama with front-projection will almost always take at least two projectors angled from the tormentor positions toward the opposite upstage corners of the cyclorama. This means that the two images will have to lap at the upstage center of the cyc—the most conspicuous part of the image. One possible solution will be for the designer to create slides that avoid linear elements in this area and to plan for the images to overlap and blur somewhat. If a really sharp image is needed stage center, it is best to go to a three-projector setup with the third projector operating on the center line of the stage.

It is instructive to note that many European stages use flat panels of cyclorama material instead of a continuous curved cyc. Distortion is easier to control and the gaps between the panels provide otherwise impossible upstage entrances. The designer must take the corners formed where the panels meet into consideration when slides are being designed.