Application of 3D CAD for Basic Geometric Elements in Descriptive Geometry

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ABSTRACT

This informal study integrates the solutions in descriptive geometry with an introduction to 3D CAD approach for dealing with the basic geometric elements. The basic elements include points, lines and planes as opposed to solids. Several problems in descriptive geometry were solved using both the 3D CAD approach and the traditional approach that requires successive auxiliary views based on orthographic projection. An evaluation of both approaches was conducted. It showed that the use of 3D CAD in descriptive geometry demonstrated the effectiveness in speed and accuracy, and did not limit the use of geometric and spatial reasoning.

Introduction

For decades, descriptive geometry has been the science of graphic representation used to obtain the solutions of space problems. The fundamentals of descriptive geometry are based on the principles of orthographic projection (Paré, Love, Hill, and Paré, 1997). The solutions are usually obtained through a series of geometric manipulations with auxiliary views to determine information such as lengths, angles, and shapes. However, before descriptive geometry can be placed onto a two-dimensional paper, a series of orthographic views must be drawn to scale from which auxiliary views can be projected with accuracy. Today, CAD systems with solid modeling capabilities are becoming more popular in engineering design. They allow the user to create three-dimensional models from which the orthographic views can be easily captured with minimum user interaction. Two international researchers (Ohtsuki, et al., 1998 & Pavel, et al., 1998) have investigated the potential application of 3D CAD in descriptive geometry with diversified emphasis. The former focused on the evaluation of user interface as the later focused on the direct manipulation of working drawings. In the United States, Croft (1998) had positive comments on the need for descriptive geometry in a world of 3D modeling. He gave a number of examples on how a 3D model could be used to extract the needed geometric information without the use of successive auxiliary views. He concluded that CAD enables us to use a variety of methods to solve the problem, and it is important that the user have a sound foundation in spatial relationships and visualization so that the developed solutions are the most efficient.

Croft's study, however, focused on solids only without discussion about the application of 3D CAD on basic geometric elements including points, lines and planes. Some of the important applications in descriptive geometry require the use of these elements. For example, civil engineers, who need to construct a bridge to connect raised freeways, must deal with the shortest distance between skewed lines. Mechanical engineers, who need to lay a control cable through sheet metal with a drilled hole, are required to identify the pierce point and the angle between line and plane. Points, lines, or planes which are not part of a solid must be handled differently in 3D CAD approach compared to just solids alone. This study focuses on how to obtain the required geometric information concerning the figures that consist of these basic elements with 3D CAD approach. Both the 3D CAD approach and the traditional approach that requires successive auxiliary views are used to solve the same set of problems, and therefore, can be evaluated for their effectiveness. The software package utilized for the 3D CAD approach is I-DEAS acquired from SDRC (Structural Dynamic Research Corporation). Although the CAD description is based on I-DEAS, the functions used in this study are among the most basic for 3D CAD operations. As 3D CAD operations are becoming more universal today, the result should be the same for any software package, such as Catia, Mechanical Desktop, Pro E, SolidWorks, Unigraphics, etc.

Comparison of 3D CAD Approach to Traditional Approach

Angle between planes (Dihedral Angle)

Traditional Approach

The angle between two intersecting planes can only be measured whenever both planes appear as an edge. This will only happen in an auxiliary view where the line of intersection appears as a point. *Figure 1* depicts that the line of intersection 1-2 is projected as true length (T.L.) in the primary auxiliary view, so it can be projected as a point view in the secondary auxiliary view. By projecting points 3 and 4 to the same view, the edge view of both planes 1-2-3 and 1-2-4 are available. Therefore, the true angle (T.A.) can be measured between the two edges.

3D CAD Approach

One of the most useful features in 3D CAD approach for basic geometric elements is the work-plane, which basically consists of a coordinate system represented by a triad that contains x, y and z axis data provided by the software (Lawry, 1999). The main purpose of the work-plane is to serve as a sketch-pad. However, the sketching can only be made on its x-y plane. The procedure for 3D CAD approach is as follows:

1. Move and rotate the work-plane (in dotted line) until it is perpendicular to the line of intersection as shown in *Figure 2*. In isometric view, the perpendicularity is depicted when the line of intersection is in line with the z-axis.
2. Display true size of the work-plane that is made available through "eye direction" (an I-DEAS command) given in *Figure 3*. Both the point view of the line of intersection and the edge view of the planes can be obtained from this direction.
3. Since the point view of the line of intersection is already on the work-

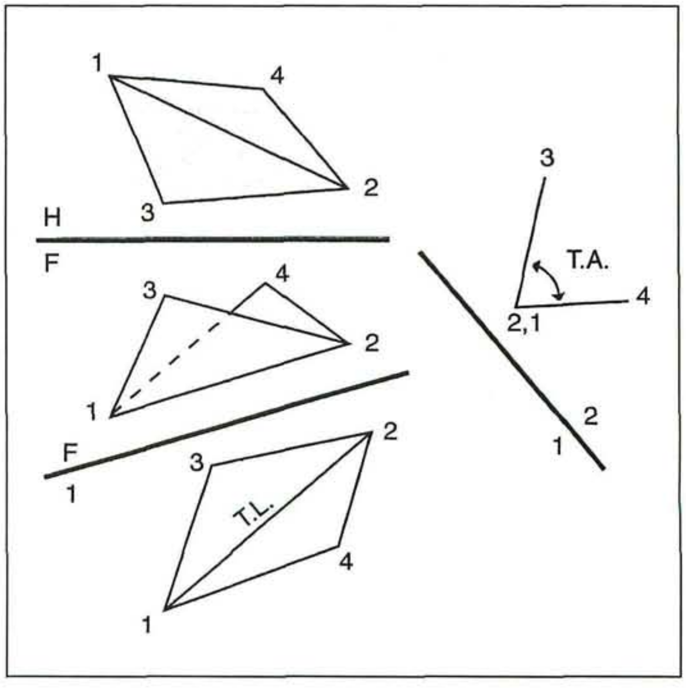

Figure 1 *- Traditional approach for dihedral angle.*

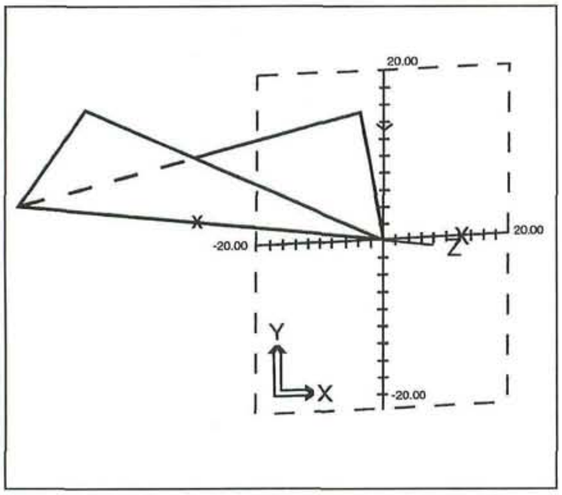

Figure 2 - *Work-plane perpendicular to line of intersection.*

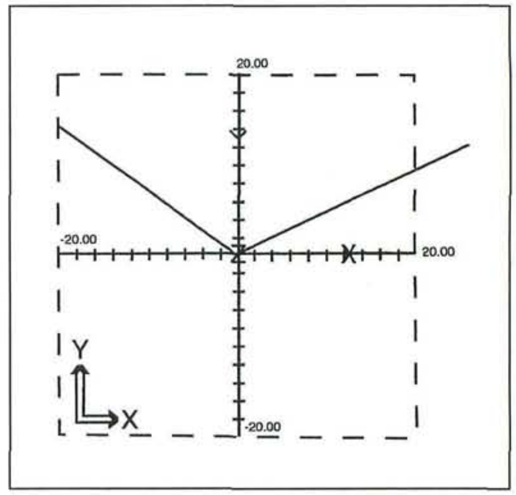

Figure 3 - *Point view of line of intersection and edge view of planes.*

plane at the origin, one just has to project the top corner point (off the line of intersection) of each plane to the same work-plane before connecting them with a straight line for the edge view. Find the angle between the two edge views by using either the "dimensioning" or "measuring" command.

Angle between Line and Plane

Traditional Approach (Plane Method)

The true angle can only be measured in the view where the plane is an edge and the line is true length. *Figure 4* shows plane 1-2-3 is projected as an edge in the primary auxiliary view off the top view. From there, plane 1-2-3 is found true shape (T.S.) in the secondary auxiliary view by projecting perpendicularly from the edge view. Then, a third successive auxiliary view is projected perpendicularly from line AB, so the line would be true length. Since a view projected in any direction from the true-shape of plane will show the plane as an edge view, plane 1-2-3 in the third auxiliary view is, therefore, an edge view. The angle between line AB and plane 1-2-3 can be measured in this particular view.

3D CAD Approach

1. Since the software doesn't allow the user to directly measure the angle between the line and the plane, the edge view of the plane must be made available first. *Figure 5* depicts how this edge, which is basically a line projected (using the "project curve" command) perpendicularly onto the surface of the plane, is obtained.

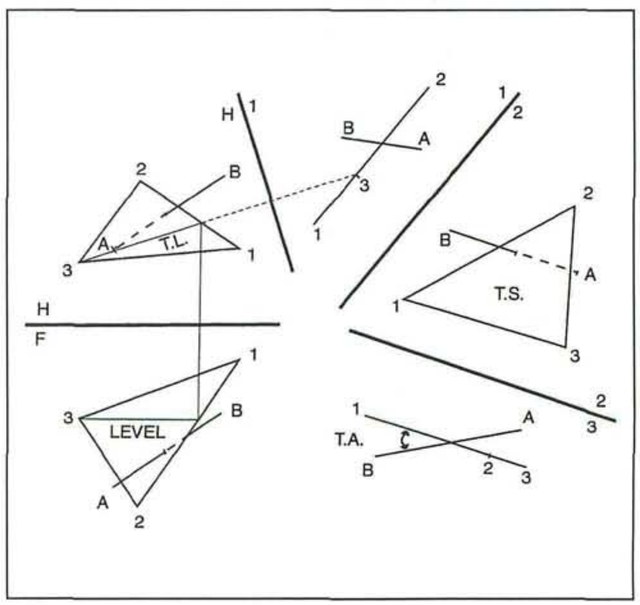

Figure 4 - *Traditional approach for angle between line and plane.*

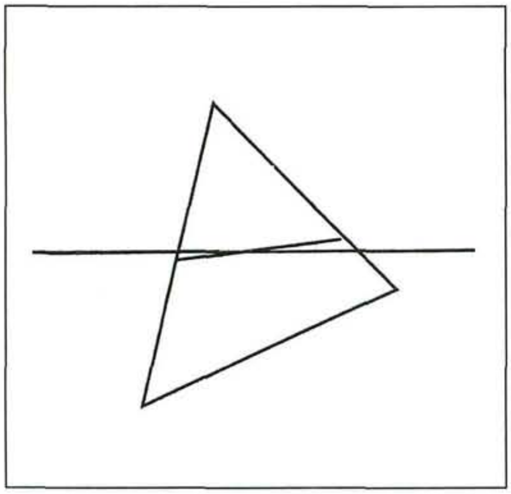

Figure 5 - 3D CAD approach for angle between line and plane, line projected onto plane.

2. The angle between the two lines, including the one representing the edge of the plane is, therefore, the angle to measure. The software's "angle by vectors" command is ideal for measuring the true angle between two lines even though it doesn't appear to be true angle in this view.

Shortest Distance between Skewed Lines

Traditional Approach

Skewed lines 1-2 and 3-4 are lines that are neither parallel nor intersecting. *Figure 6* shows how line 1-2 is found true length in the primary auxiliary view by projecting along with line 3-4 from the top view. The point view of line 1-2 is found in the secondary auxiliary view projected from the true length. The shortest distance between two skewed lines can be found in the view where one of the lines appears as a point. Therefore, the shortest distance in this case is the same as the perpendicular line from the point view of line 1-2 to line 3-4.

3D CAD Approach

1. Move and rotate the work-plane as shown in *Figure 7*, so it is perpendicular to one of the two skewed lines at the origin.
2. After the point view of the skewed line (at the origin) is obtained by using the "eye direction" command to display true size of the work-plane, sketch the shortest distance from the point view of the first skewed line to the other skewed line as depicted in *Figure 8*. The shortest distance must be sketched on the work-plane. This can be achieved by placing one end point at the point view of the skewed line, and the other end point focusing on the other skewed line even if it is not on the same work-plane. The end point can be snapped through dynamic navigator to the second skewed line whenever the line to be constructed appears perpendicular. These all can be easily done by using the perpendicular constraint in the navigator controls provided by the software.
3. *Figure 9* represents the same figure as it is displayed in isometric view. It is easy to see that in reality the shortest distance is not connected to the second skewed line, because it is sketched on the work-plane, and, therefore, not at the correct location. *Figure 10* repre-

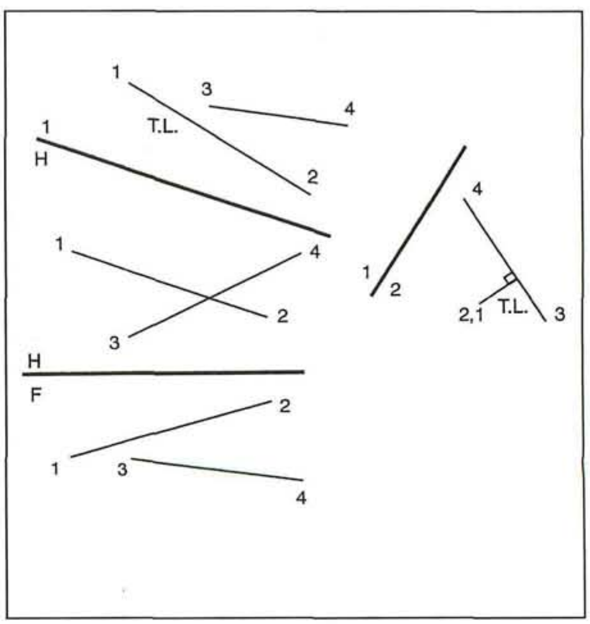

Figure 6 - Traditional approach for shortest distance between skewed lines.

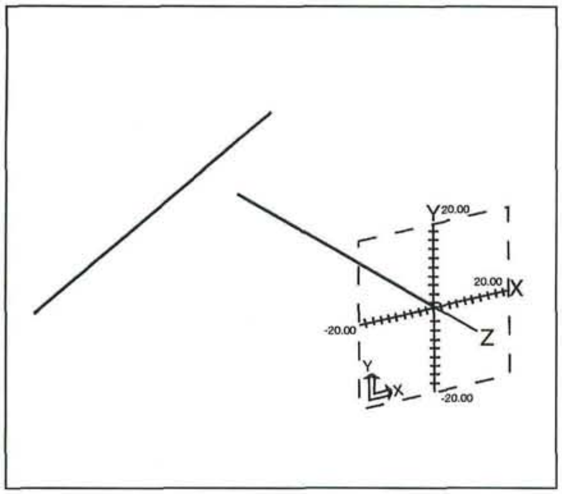

Figure 7 *- Work-plane perpendicular to one of two skewed lines.*

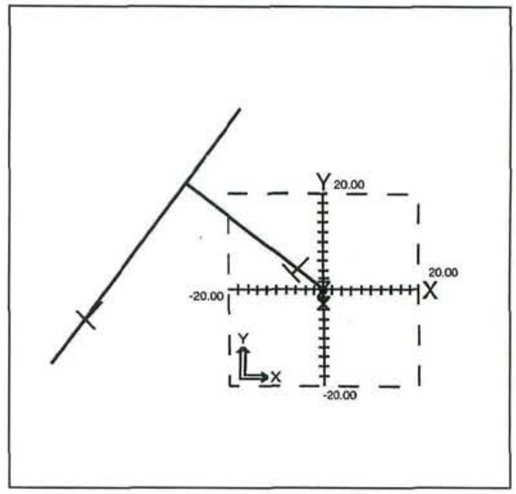

Figure 8 *- Shortest distance perpendicular to skewed line from point view.*

sents the completion of the solution as the shortest distance is moved (along the first skewed line) so both skewed lines can be properly connected.

Shortest Horizontal Distance between Skewed Lines

Traditional Approach

This approach, which must be based on the plane method instead of the line method (Earle, 1984), begins with the construction of a plane to include line 1-2 and allows 1X be parallel to line 3-4 as depicted in both the top and front views in *Figure 11*. This plane is projected to the primary auxiliary view as an edge off the top view. Lines 1-2 and 3-4 will appear parallel in this view. The secondary auxiliary view can be set up by projecting parallel to the horizontal plane (the same as the folding line between the top and primary auxiliary views). The point view of the shortest horizontal distance (MN) will be at the crossing point of the two skew lines in the secondary auxiliary. This crossing point would permit both true length and location of this distance to be found in the primary auxiliary view as shown in the figure. Line

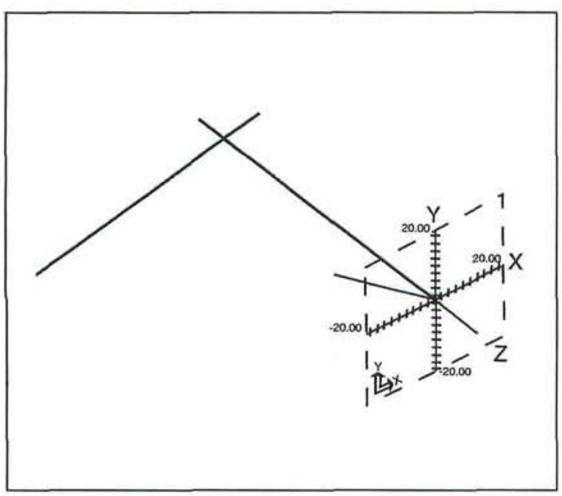

Figure 9 *- Isometric view of shortest distance sketched on work-plane.*

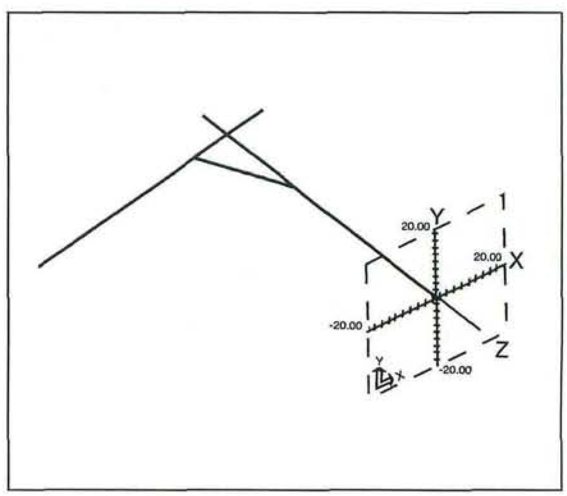

Figure 10 *- Shortest distance moved to connect skewed lines.*

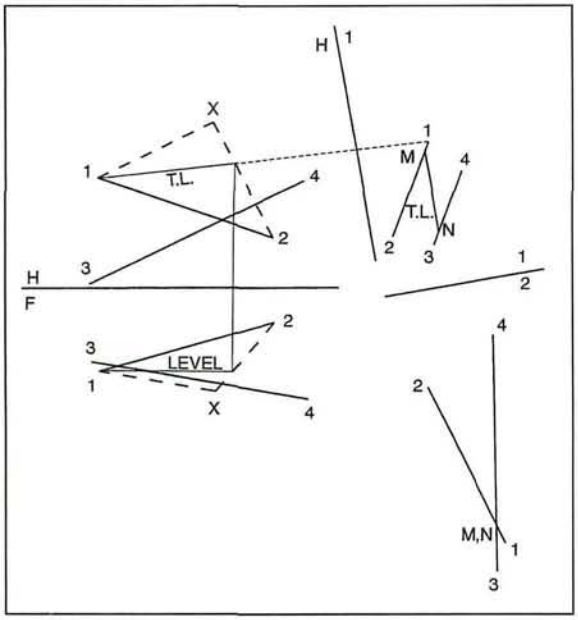

Figure 11 - Traditional approach for shortest horizontal distance between skewed lines.

MN should appear as a level line (not shown) that connects lines 1-2 and 3-4 in the front view.

3D CAD Approach

1. Move the work-plane until it contains one of the skewed lines as shown in *Figure 12*. Rotate the work-plane if necessary, but make sure the x-axis stays horizontal.
2. Rotate all including the work-plane (with dynamic viewing) until the x-axis appears as a point given on the left of *Figure 13*. In the figure, the y-axis overlaps with the skewed line contained by the work-plane.
3. Slide the point view of x-axis along the skewed line until it is at the crossing point of the two skewed lines given on the right of *Figure 13*. The point view of the shortest horizontal distance should be at this crossing point.
4. *Figure 14* shows the isometric in which a new coordinate system is made available. With this new coordinate system, one can sketch on the x-y, y-z, or x-z plane instead of on the x-y plane alone for the work-plane. The purpose is to allow the shortest horizontal distance to be sketched on the x-z plane (using "sketch on the surface" command) of this new coordinate system.
5. Since the shortest horizontal distance must be on x-z plane, its end points can be located at the intersection of each of the two skewed lines and x-z plane. The problem can be completed by sketching and measuring the distance between the two end points for the shortest horizontal distance as depicted in *Figure 15*.

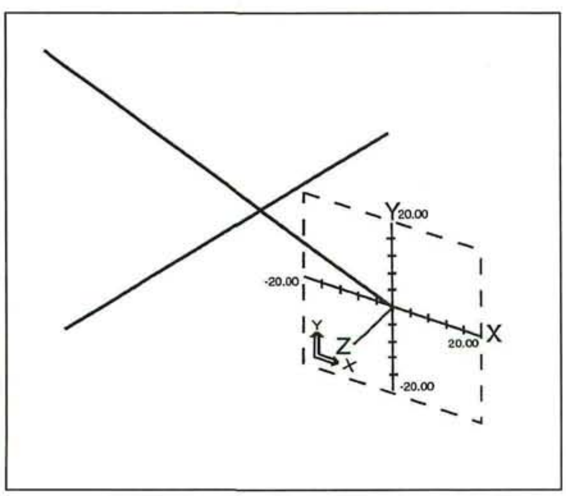

***Figure 12** - Work-plane contains one of two skewed lines.*

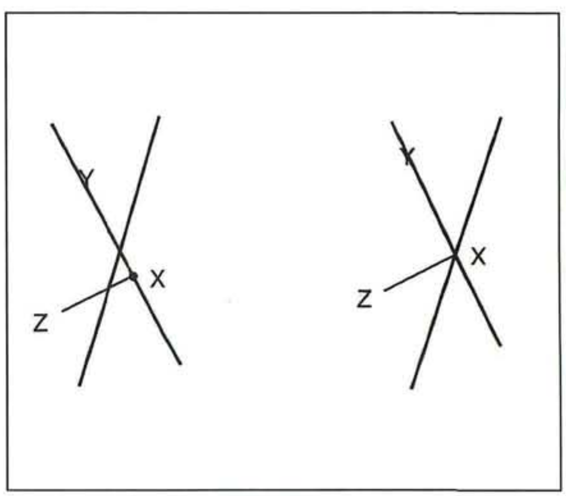

***Figure 13** - Point view of X-axis (left) and point view of X-axis aligned with crossing point of skewed lines.*

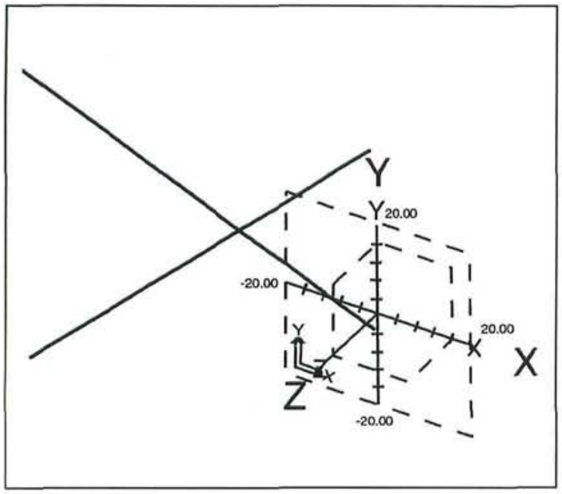

Figure 14 - *New coordinate system.*

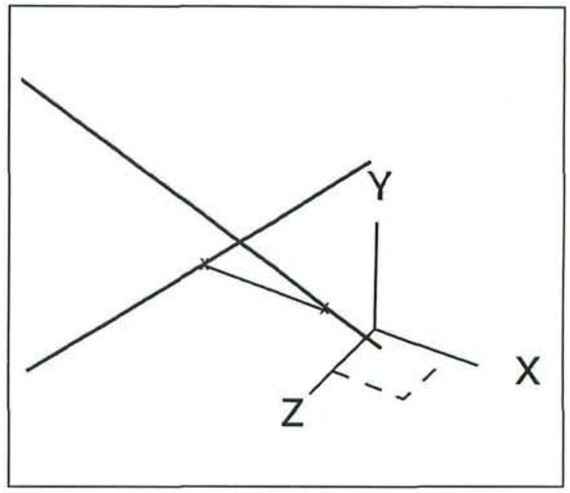

Figure 15 - *Shortest horizontal distance between points at intersections of skewed lines and X-Z plane.*

Discussion

The problems in the previous section prove that the 3D CAD approach is much more effective in dealing with basic geometric elements in most cases. This effectiveness is clear in each of the first three problems presented. The 3D CAD approach is more accurate yet less time-consuming, because it just requires the application of a few CAD commands instead of the manual construction of successive auxiliary views. Successive auxiliary views based on orthographic projection, which are the foundation of the traditional approach for descriptive geometry, are not necessary for the 3D CAD approach. Instead, the work-plane is manipulated through translation and/or rotation to obtain the needed geometric information. Although the level of success for 3D CAD approach is closely related to the effectiveness of work-plane manipulation, sound spatial reasoning is still required. This can be easily seen in the problems provided - either the point view of a line or the edge view of a plane must be made available before the solution could be completed.

In general, a problem that deals with the basic geometric elements associated with "planes" is much easier to solve with the 3D CAD approach. The more direct approach in the first two problems proves so. A problem that deals with basic elements rather than planes requires a few more CAD commands – but still with significant amount of time saved as compared to the traditional approach. This is evident from the third problem. The fourth problem requires a little more CAD work due to its complexity. In this particular problem, it is hard to determine which of the two approaches is superior. If one must say that 3D CAD is more efficient, it is probably due to its ability to serve as an electronic pencil. Regardless of the various amount of CAD work required for each of these four problems, it is easy to see that the use of 3D CAD approach doesn't limit the use of geometric and spatial reasoning. As a matter of fact, the concepts and geometric rules have not changed regarding descriptive geometry solutions.

With the 3D CAD approach, most problems with basic geometric elements can be solved as efficiently as the first three problems. These include the following problems:

a. shortest distance between point and line.
b. shortest distance from a point to a plane.
c. angular distance from a point to a line.
d. true shape of a plane.

All of these can be easily solved following the similar 3D CAD approach presented in this paper with minimum modifications.

Conclusion

As 3D CAD software packages are getting popular due to their high performance, the training in descriptive geometry is forced to change greatly. The training of the spatial reasoning, in either solid or basic geometric elements, can no longer be limited to only the 2D traditional approach. Instead, the training of the construction skill must be shifted to CAD systems. The 3D CAD approach demonstrates the effectiveness in both speed and accuracy. Descriptive geometry helps overcome complications and formalize solutions to spatial problems. The 3D CAD approach using a computer certainly expands this capability with minimum user interaction.

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