Reflection Lines: Shape in Automo

Reflection lines are an important tool for judging shape in automotive design. Gerald and Dianne look at the evolution of the design cycle, and argue that shape analysis tools in CAD (Computer Aided Design) have played an important role in revolutionizing the design cycle.

How can we measure the beauty of a car's shape? To some extent, this judgment is subjective and depends on current fashion trends. However, in the auto industry there is one fundamental measure that is accepted by all designers, whether they are dealing with a bulbous Neon or a boxy Volvo. Reflection lines are this measure, and we will describe their real-life existence and a popular method of simulating them for CAD (Computer Aided Design). We'll begin by looking at the automotive design process, which in turn motivates the need for such a shape analysis tool.

Evolution of Automotive Design

The beginnings of CAD-based automotive design date back to Paris in 1959, when the car company Citroën hired a young mathematician, Paul de Faget de Casteljau. Citroën already had computer controlled milling machines, but in order to fully utilize them, a link had to be created between the then prevalent 2D blueprints and the milling machines. This link would have to translate the blueprint information into formulas, thus creating the coordinates to drive the milling machine. Pierre Bézier (a mechanical engineer) worked at Renault, also in Paris, and learned about Citroën's (very secretive) efforts. He was able to create a system with the same functionality himself. Independently, Carl de Boor advanced similar techniques based upon practical experience at General Motors.

These new CAD methods were incorporated into the automotive design process. Until the late 1980's the process basically consisted of the following steps.

1. Artistic 2D sketches capture the concept.
2. Clay prototypes are built to interpret the sketches.
3. A 3D CAD representation is developed by digitizing the clay prototypes and transforming this information into extensive mathematical formulas.
4. Milling instructions are generated from the 3D CAD model.

The CAD model is employed in many engineering tests, such as airflow and strength analyses. Also, the CAD model is key to the specification of milling instructions. It is not uncommon for an initial design to fail one aspect of engineering. If major unforeseen changes were necessary, common practice was to rebuild the clay model and then rebuild the CAD model. This cycle was very expensive, time-consuming and dampened creativity.

Although the mathematical tools of de Casteljau and others would allow artists to completely design autos using CAD, computer hardware and haptic tools were not mature enough to make this

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tive Design

feasible. (Haptic tools give people a sense of feedback or touch. Examples of these tools are on Brown University's haptic research page **http://www.cs.brown.edu/research/graphics/research/haptics/home.html** and at Immersion TouchSense™ **http://www.immersion.com**). Also at issue was the matter of confidence in a computer image; the prototypes allowed a certain sense of security. Slowly, over the years, familiarity with CAD and better hardware allowed CAD's role to grow.

The Japanese automakers were the first to remove the clay model from the design process. As a result, in the late 1980's Japanese automakers were introducing new vehicles in half the time of Detroit automakers. Decreasing the design cycle span significantly reduced costs. Furthermore, creativity could flourish in this environment, leading to a greater variety in designs. As a result, practically all automakers have adopted CAD design tools, which in turn have minimized the importance of the clay prototype.

Elimination of the clay model necessitated tools to analyze the 3D CAD model. In particular, these tools needed to simulate the methods applied to the clay model. After all, the clay prototype had a reassuring feel to it. The most important analysis tool is the use of reflection lines.

Reflection Lines

Figure 1 below illustrates real-life reflection lines. Many high-end automakers employ reflection lines as a quality assurance tool, just before the car leaves the factory.Sets of parallel, long and thin light bulbs are set up in an otherwise dark room. The reflections of the light bulbs in the car are observed by technicians walking around the car. In a door panel, for example, the reflection lines should appear as smooth curves on the car. An unexpected ripple most likely means a dent in the door. This same technique was also applied to the clay model, which was painted in order to be reflective.

Figure 1. Real-life reflection lines used as a quality assurance tool.

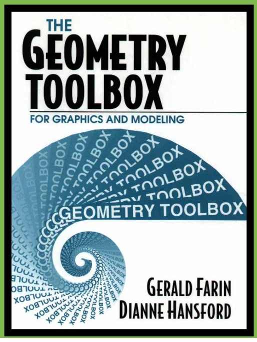
Reflection lines are a function of your position, the car's position, and the position of the lights. When a car's surface is nicely polished, it behaves just like a curved mirror. The laws of optics are still valid; they're just more complicated than for a plane mirror.In a CAD environment, the reflection lines have to be computed: the real-life situation has to be simulated.

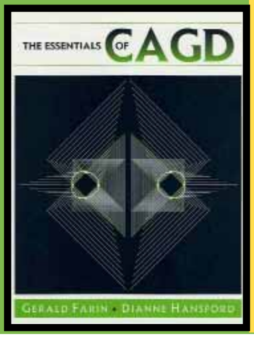
Since every part of the car is stored in the CAD model as a mathematical formula, the simulation of reflection lines is reduced to solving a few equations. They involve: the observer's eye position (given by its x,y,z-coordinates), the position of the line light source (given by a 3D line equation), and the car's surface (given by a fairly complex set of equations). The geometry behind this computation is outlined in **Figure 2**.

It shows the geometry for a point on the surface where an observer sees a reflection. For such a point, the display program would then assign a bright white color to the surface. For points where a reflection is not seen, the standard color of the surface is chosen. This color is darker than the white reflection color. The simulation now determines the correct color value for a large number of points on the surface. Displayed together, they give the impression of a reflection line. If we apply this method to a set of several light lines, we obtain a simulation as shown in **Figure 3**.

Figure 4 shows how sensitive reflection lines are as an analysis tool. The surface from **Figure 3** was only slightly perturbed, but the resulting pattern of reflection lines reacts quite noticeably: this set would not meet design specifications!

More technical details on the vector operations necessary for these calculations may be found in ***The Geometry Toolbox***, and a complete reflection line algorithm may be found in ***The Essentials of CAGD.***





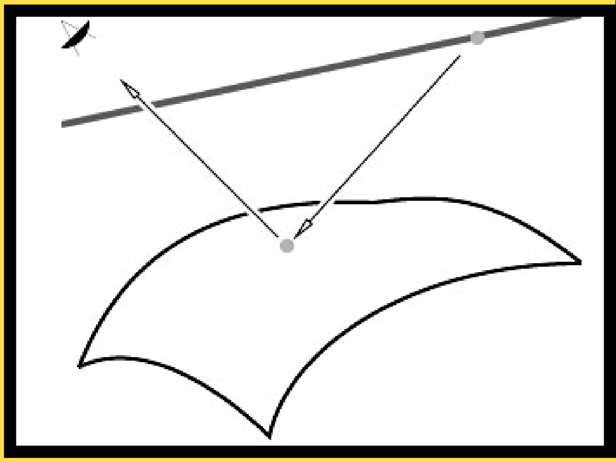


Figure 2. Computation of a reflection line.

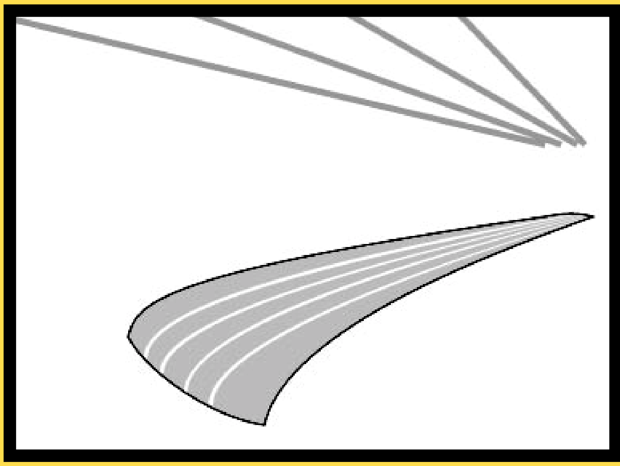


Figure 3. A set of reflection lines.

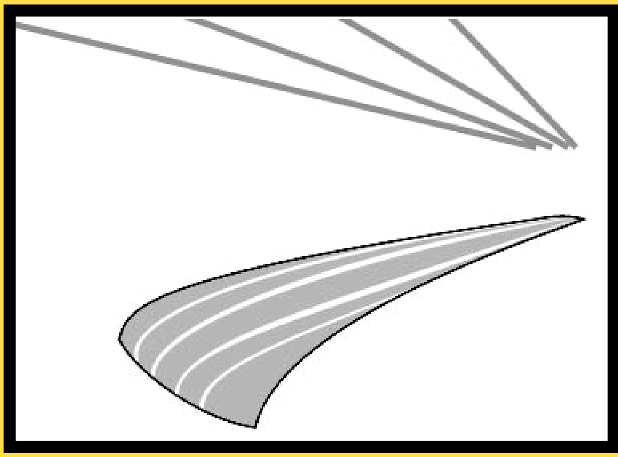


Figure 4. A set of “bad" reflection lines.

Conclusions

Reflection lines, real-life and simulated, are a key shape analysis tool in the automobile industry. The role of CAD in the design process has greatly increased in part due to the ability to simulate this familiar tool. With CAD's role increased, the design cycle has been greatly reduced, which in turn has resulted in cost savings and more creative auto designs.

Reflection lines are not the only shape analysis tool employed in the auto industry. Curvatures of surfaces are also a popular tool. In fact, reflection lines and curvatures are used as shape analysis tools in a variety of disciplines. See the 3D Knowledge project **http://3dk.asu.edu** for some examples.

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Gerald and Dianne are also authors of *The Geometry Toolbox*, AK Peters, 1998, and *The Essentials of CAGD*, AK Peters, 2000.

Project Ideas

Reflection lines can be observed in parking lots. A parking structure with light strips is one possibility. An outdoors parking lot with white lines delineating the spaces will work too. If the sun is in a low enough position, the white lines will be reflected onto a car. Notice that the reflection lines accentuate defects on a surface. A dent will result in a distorted reflection line.

Consider the “perfect" set of reflection lines in **Figure 3**. If you put a slight dent in the surface by punching it from above, how will the reflection lines change?

Reflections also occur in other areas of life. If you look at a reflecting high rise building, you will see neighboring buildings reflected in it. Slight imperfections in the glass panels of the building will be visible through these reflection patterns. This is more accentuated if you view the building from a greater distance. Why?