Application of Smooth Surface in Vehicle Design
Mu-rong CAI and Tian-jian CUI
School of Art, Southeast University, Nanjing 210000, China

Keywords: Smooth surface, Product modeling, Science and art unity.

Abstract. From the perspective of product shape description, analyzed the smoothness of curves and the formation of curved surfaces. Discussed the properties of smooth surfaces. Investigated the influence of key parameters of smooth surface in product design aesthetically and scientifically from which it can be concluded that smooth surface is fruity, fluid, smooth and beautiful, in accordance with the principles both aesthetics and multidisciplinary science. Examples of aerodynamics and aesthetics analysis on the design of vehicle presented indicate that not only smooth surface does make product beautiful but also improve its performance and it embodies the unity of science and art.

Introduction
At the beginning of the 20th century, Bauhaus advocated the functional doctrine of "form follows function", emphasized design function and practicality and opened up a new direction for the modern product design. The requirement of combination of art and technology made the modern design turn gradually from idealism to realism and substitute artistically free expression and romanticism with rational and scientific theory. With the further development of science and technology, people's aesthetic requirements for product appearance were raised which will promote the development of surface form. In the 1930s, the use of "streamlined style" surface products sprung up. In 1960s to 80s, as the continuous coordination of streamline design and scientific theory, the streamlined style became the mainstream again. It was drawn out from the boring geometry of the form, developed into a simple, smooth and dynamic surface form which led to the creation of a new design atmosphere for the form of rational decorative elements and the change of the traditional style of modernism. From 90s to the present, the application of computer aided design has prompted further fusion and improvement of diverse curved surface and structural function. Rational language embodied in the product makes appearance more expressive and persuasive\[^{[1]}\]. With the progress of the times, products with curved surface modeling has been promoted and extended further.

The application of curved surfaces in art design has always been attractive. But from the perspective of the unity of science and art, the relevant research is very rare. In recent years, china’s products of transport and machinery have been developing rapidly, many of which are in the transformation stage from surveying and mapping to independent development. Aircraft, rockets, high-speed trains, cars, etc. are characterized by high-speed and heavy load and how to apply smooth surface to them so as to make them to be of both superior functional quality and beautiful appearance and to achieve the perfect unity of science and art is an important issue.

Smooth Surface Analysis
Formation of Curves
Kandinsky pointed out: "point, line, surface is the most basic form of the art of language and unit. It not only has the characteristics of symbols and graphics, but also can express different personality and rich connotation. Its abstract form, to give the essence of art and the extraordinary spirit\[^{[2]}\]. Various types of appearance expression form are interwoven and correlated with elements of point, line, surface, block, etc. As the initial foundation of the appearance expression form, point is the minimum expression form in the modeling world. One point locates in space’s a spot, has no specific value. A line is the locus of a continuously moving point or is formed by an infinite number of ordered points. The former gives people a sense of motion but the latter gives people a sense of quiescence.
Line as an appearance expression form can be divided into straight line and curve. A line is formed by the motion of a point in a given direction, when the motion direction of the point changes, its trajectory is a curve. The shape of the curve can be described by its continuity. Continuity of a curve includes 0 order (C0) continuous, that is, there is no breakpoint on the curve, first order (C1) continuous, that is, its first order derivative continuous and nth order (Cn, n=2,3,…,n) continuous, that is, its nth order derivative continuous. The calculation formulae of the first order derivative $y'$, second order derivative $y''$ and curvature $\rho$ of a curve are expressed mathematically as follows:

$$y' = \frac{dy}{dx} \tag{1}$$

$$y'' = \frac{dy'}{dx} = \frac{d^2y}{dx^2} \tag{2}$$

$$\rho = \left| \frac{((1 + y'^2)^{\frac{3}{2}})}{y''} \right| \tag{3}$$

where $y$ is a function of $x$, symbol "d" means differential.

When the first order derivative of a curve is constant, means the movement direction of the point is invariable and it is a straight line. The smaller the absolute value of the derivative of a curve is, the closer the direction of the moving point to the horizontal, the greater the absolute value, the closer to the plumb line. The greater the curvature of a curve is, the more sharply the curve bends, the smaller the curvature, the more gently the curve bends. Figure 1 illustrated the continuity of curves. As shown in figure 1 a), the curve is broken at $k$ and it is C0 discontinuous at $k$. As shown in figure 1 b), the curve is not broken at any point and it is C0 continuous but it is sharp at $k$, so it is C1 discontinuous at $k$. As shown in figure 1 c), the curve is neither broken nor sharp at any point, it is C1 continuous, but it exists a straight line segment whose second order derivative does not exist, so the curve is C2 discontinuous. Figure 1 d) shows a C2 continuous spline curve.

![Figure 1. Continuity of curves.](image)

![Figure 2. Various surfaces.](image)
Formation of Curved Surface

A surface is geometrically defined as the trajectory of a continuously moving line in space under specified condition. According to the different shape of the generating curve, the surface is usually divided into ruled surface, curved-profile. The ruled surface is formed by moving a straight generating line, see figure 2 a) and b). A curved-profile is formed by moving a generating curve, as shown in figure 2 c). In addition, according to the different forms of the generating curve moving mode, the surface is divided into the revolving surface and non-revolving surface. As shown in figure 2 d), a revolving surface is formed by the rotating a generating curve around a fixed axis. A non-revolving surface is formed by moving a generating curve with changing shape along a guide line, figure 2 e) shows a non-revolving surface. The smoothness of a surface means that the local shape of it does not change sharply. A curved surface can be considered to be formed by infinite curves, so the smoothness of a surface can be analyzed by analyzing the smoothness of curve on it.

By analyzing the curvature of a curve it can be known that to be a smooth curve, it should be C1 continuous, that is, it neither has any broken nor any sharp point, this is the necessary condition. As shown in figure 3, two straight lines are connected by an arc. With the decrease of the curvature of the arc, the curve becomes more and more gentle. When the curvature of the arc equals 1, it turns sharply when goes from point A to point B. When the curvature equals 0.33, it turns less sharply and when the curvature equals 0.125, it turns gently.

![Figure 3. Curves with different curvatures.](image)

Any point on a curved surface has two principal curvatures, the minimum principal curvature and the maximum principal curvature, they reflect the smoothness of the surface at that point.

**Design Aesthetics and Scientific Representation of Surfaces**

Different surface form will bring people utterly different psychological feelings. As shown in figure 4, surface with large curvature causes insecurity of sharp and stabbing. Figure 5 shows a revolving surface with large curvature at its tip but the curvature continuously and smoothly decreases along the axial direction which provides a sense of motion with high speed. As shown in figure 6, a curved surface with small curvature, provides with fruity, gentle, mellow and comfort sense of safety and the association with curvy figure of beautiful women strengthens the sense of kinship and sex appeal.

![Figure 4. Cone with large curvature at the tip.](image)  ![Figure 5. Curved surface with large curvature at the tip.](image)

In the design of aircraft, rockets, aero engines, high-speed trains, cars and other high-end mechanical products, the theories and methods of aerodynamic science and strength science are usually applied. From point of view of aerodynamics, when air flows along the tangential direction of a curved surface, the aerodynamic drag and loss are small. In order to reduce aerodynamic drag and loss, the area with the normal of the surface parallel to the inflow direction should be reduced as much as possible.

As shown in figure 7, a small zone with large curvature of a curved surface towards the inflow is effective to reduce the aerodynamic loss. On the surface, large curvature should transit smoothly to
small curvature in the flow direction. Curved surface with small curvature is conducive to maintaining the flow to be laminar and to avoid turbulence, so as reduce the aerodynamic losses.

From the point of view of strength science, for a loaded structure, the local zone with large surface curvature usually causes stress concentration which decreases the static strength and the high cyclic fatigue strength. So structure with large surface curvature should be avoided. Figure 8 a) shows a segment of a shaft with two circumferential grooves, the left one has large curvature and the right one has smaller curvature. Figure 8 b) shows the stress distribution of the segment, the maximum stress of the left groove with large curvature is two time of that of the right one.

From above description it can be seen that smooth surface not only beautiful on appearance, meets the requirements of design aesthetics but also meets the design requirements of aerodynamic science and strength science principle.

Application of Smooth Surface in Vehicle Appearance Design

Smooth surface is fruity and smooth and is the best choice of the comprehensive optimization of multidisciplinary science. It meets the cutting-edge products design requirements derived from the scientific principles of different disciplines and it is a product appearance form that embodies the perfect unify of science and art, to which the following examples illustrates further.

The early cars were simple and with square and upright appearance. Structures featured as right angled flat surfaces, for instance the early Rolls-Royce car shown in figure 9. The design and manufacture level was low in the early car industry, the travel speed of cars were slow, met the basic requirements of people’s travel and transport at that time. With the development of internal combustion engine technology, speed of vehicle became faster and faster. The problem of aerodynamic drag of this appearance form of the old car gradually revealed out.

Figure 10 shows the wind tunnel test computer simulation velocity vector diagram of the early car where arrows are pointing to the direction of the flow and the longer the arrow, the faster the speed at that point. If the direction of the air flow is parallel to the tangent plane of the surface, the aerodynamic drag will be small. On the contrary, if the direction of inflow is perpendicular to the normal line of the surface, the aerodynamic drag will be large. Thus it can be seen that the flow is
flowing along the surface on the upper and lower surface shown in figure 10, the aerodynamic drag is small there, but the front part of the car and the front window section are perpendicular to the direction of the inflow and it can also be seen that large eddy current is formed in front of the window and the speed of the flow at the rear of the car is very low. All of these elements increase the aerodynamic drag and loss. It is not in conformity with the requirements of aerodynamics. Moreover, the appearance of the early cars looks a little dull and not beautiful enough and does not meet the aesthetic requirement, it is of scientifically and artistically low-level.

![Figure 11. Birdcage.](image)

![Figure 12. Simulation velocity vector diagram of Birdcage.](image)

Figure 11 shows Martha Lahti concept car, Birdcage which seeks to capture the ultimate expression of speed, sensuality and elegance. It has an extremely streamlined and efficient frontal area and an exceptionally low profile to aid in the air flow above and under the vehicle.

Figure 12 shows the wind tunnel test computer simulation velocity vector diagram of Birdcage. It can be seen as compared with figure 10 that the flow can flow smoothly along most of the surface of the car which decreases the aerodynamic drag and meets the aerodynamic design requirements. Moreover, the smooth surface of the vehicle captures the ultimate expression of sensuality and elegance indeed and it is superior both in science and art.

**Conclusion**

The characteristics of the curve and curved surface are analyzed. The design aesthetics and scientific expression of the curved surface and its application in product design are investigated from which the following conclusions can be drawn:

1) The appearance of fruity, fluid and smooth curved surface is elegant and beautiful. It meets the requirements of design aesthetics and it is also the results of the comprehensive optimization of multidisciplinary.

2) Smooth surface is usually the best expression form of product appearance based on the highly unified science and art. To obtain high quality and beautiful appearance of a product, reasonable distribution of curvature on curved surface is a key factor when apply curved surface to design of the product.

3) In the design process of high-end mechanical product, it should be consciously combined with the theory of science and art, and achieve the perfect unity of science and art on the product.

**References**


