

## **AC 2007-1163: SURFACE MODELING TECHNIQUES FOR AUTOMOTIVE AND PRODUCT DESIGN**

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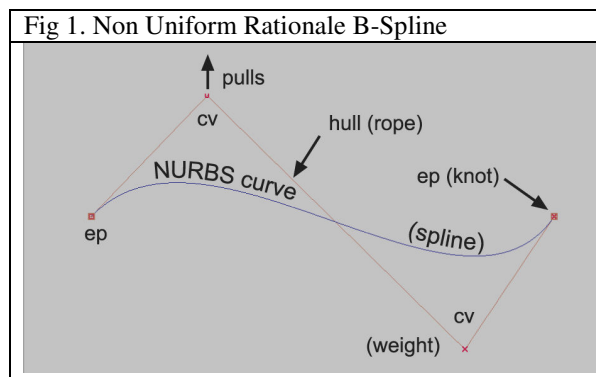
## Surface Modeling Techniques for Automotive and Product Design:

Autodesk's recent acquisition of Alias adds the industry leading computer aided industrial design software, Alias Studio Tools, to its' software arsenal. A practical understanding of this sophisticated surface modeling program is beneficial to engineering graphics students interested in careers in automotive and consumer product design. The software provides complete NURBS based curve and surface control, and advanced surface curvature analysis and rebuilding tools. With many tools and technical surfacing techniques the software has a very steep and intense learning curve. For users to be able to create efficient seamless surfaces the user also needs a good working knowledge of curvature continuity theory. To help prepare engineering graphics students for technical modeling careers, this paper introduces NURBS curve degree, surface curvature continuity, surface analysis and continuity rebuilding techniques.

This paper outlines the major curve and surface theories mentioned above by illustrating how these theories can be practically applied to model a concept car. These concepts and example car model were recently created and used by the author, to teach an Advanced Product Design class within the Digital Media Program at East Tennessee State University. Students enrolled in the course were able to achieve: industry-level, portfolio quality surface models of their concept car designs. While the production workflow presented in the paper is specific to Alias Studio Tools, the curve and surface curvature theories are relevant to all 3D NURBS surface modeling programs. Both the authors' and student 3D models and photorealistic renders are to be shown during the presentation of the paper.

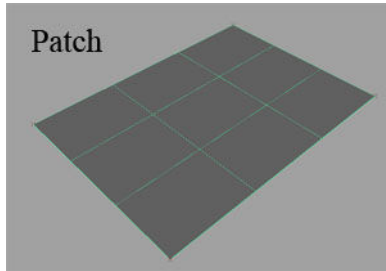
### NURBS Curves

Automotive and Product Design digital surface modeling methods primarily utilize NURBS Curves to create sets of curves that define the form of the intended surface shape. NURBS stand for Non Uniform Rationale B-Splines. NURBS curves are created and shaped by placing edit points (ep's) and positioning control vertices (cv's).



Derived from ship-building practices, NURBS curves, are like curved “wood” *splines*, that have *hulls* or “ropes” tied to a curve at its *edit points* or end points to form “knots”. Edit points or knots are always positioned on the curve or spline. *Control vertices* or “weights” are tied to the ropelike hull. Control vertices are weighted control points that reside *off* the curve, and on hulls. Control vertices influence the shape of the curve by pulling on knotlike edit points. Both the position and weight of the cv's bend the curve.

## Surfaces Patches



Surface creation tools such as: revolve, skin, rail, and square are used on NURBS Curves to form NURBS Surfaces. A single NURBS surface is called a patch and is always four sided. Complex surface models such as those of a car or product are made up of multiple patches or surfaces. The challenge in multi surface patch modeling is to create surfaces that flow smoothly into one another so that the shared border edge of patches is smooth and appears seamless.

## Surface Efficiency

The first step in creating smooth and seamless NURBS surfaces is to create efficient curves for surfaces. Efficient curves use the least amount of edit points and a minimum of 6 or more control vertices to shape the curve. Edit points that reside along curves actually divide their curve into small curve parts or segments called curve spans. Internal edit points will form surface contour lines called isoparms along the surface patch. Edit points and surface isoparms increase processing time and constrain the ability of the user to edit the surface shape by moving cv's.

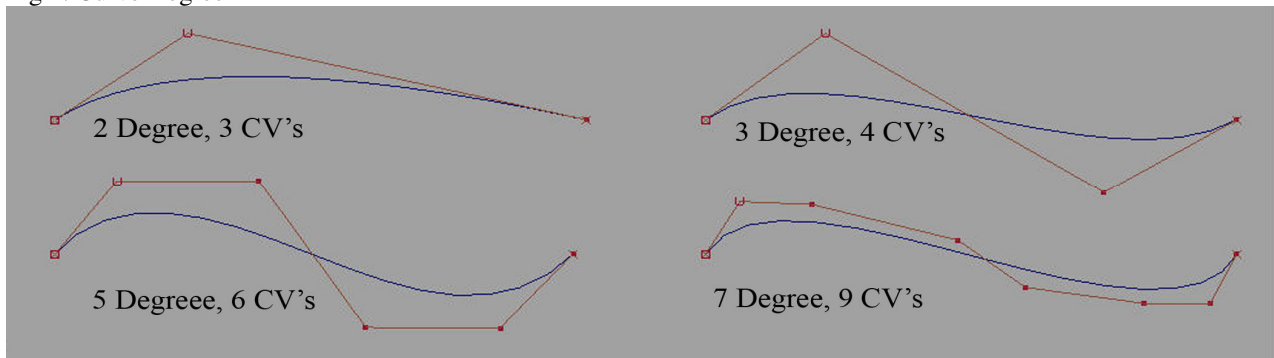
## Curve Reuse

When two or more curves with an unequal number or unaligned position of edit points are used to create a surface the resulting surface will have extra surface isoparms. One isoparm is added at each additional or misaligned edit point. This irregular surface result is known as cross knot insertion. To avoid this problem, the user should create and shape the 1<sup>st</sup> curve and then copy and move it to create the 2<sup>nd</sup>. The 2<sup>nd</sup> curve's cv's are then repositioned to reshape the curve.

## Curve Degree

To create curves that form smooth seamless surfaces it is best to increase the curve degree or the number of control vertices for the curve. Curve degree is number of control vertices for the curve minus one. A 3<sup>o</sup> curve contains 4 cv's (4 CV's-1=3<sup>o</sup>). To minimum three dimensional curve is a 3<sup>o</sup> curve. Note that a curves edit points (points at the start and end of curves) are actually counted as CV's when calculating curve degree. To help users control curve degree, studio tools has the ability to both set and change the degree of curves. A higher number of cv's is needed to form surface patches that are smooth and seamless at their border edges. 5<sup>o</sup> curves are used in product design while 7<sup>o</sup> to 9<sup>o</sup> curves are used in automobile design.

Fig 2: Curve Degree

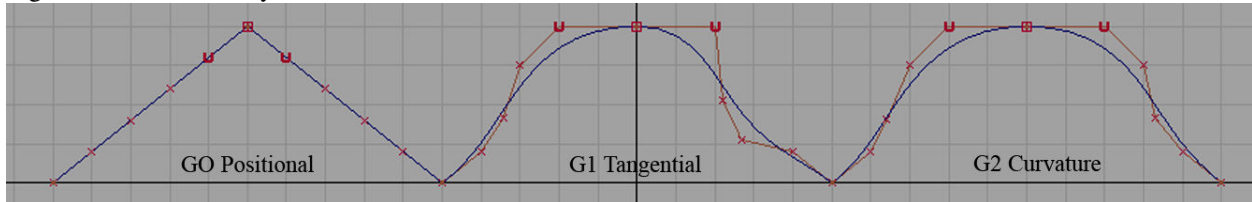


## Curvature Continuity

Since curves are used to form surface patches, the curves control the surface shape and how well the surface patches flow into one another. In order for multiple NURBS patches to appear seamless they must meet the following three types of continuity.

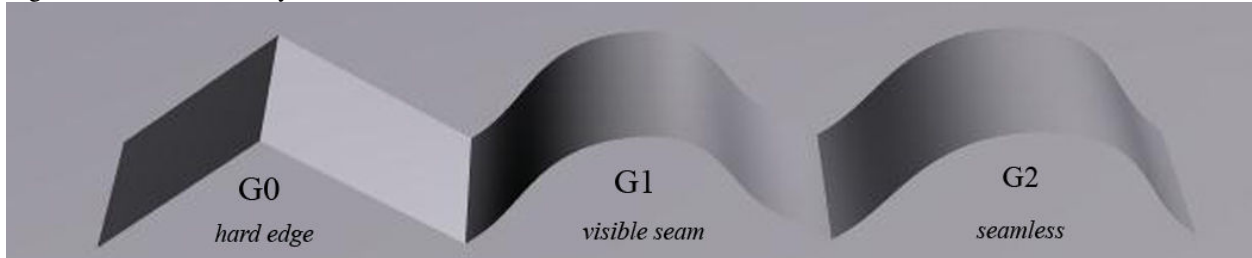
1. G0, Position Continuity: The 1<sup>st</sup> CV or edit points of each curve are at the same location.
2. G1: Tangential Continuity: The 2<sup>nd</sup> CV's or tangent cv's must be on one line.
3. G2: Curvature Continuity: The 3<sup>rd</sup> CV in both curves have the same or equal radius.

Fig 3a. Curve Continuity



In G1 continuity, the two curves are tangent to one another at their end edit points. They may still have very different apparent "speeds" or rate of change, also called curvature. G1 surfaces may have visible seams. In G2 continuity, the curvature of the two curves matches at their common end edit points. The two curves appear to have the same "speed" at the join and as a result surface made from them will flow smoothly and seamlessly into one another. Since 5° curves have six control vertices the technical surface modeler can achieve curvature continuity, on both ends of the curve, by positioning the three control vertices at each end of the curve.

Fig 3b. Surface Continuity


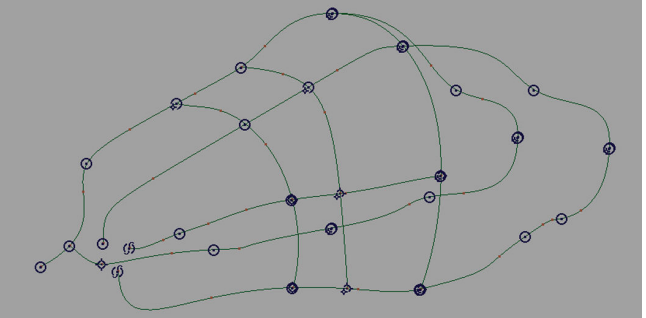




## Surface Continuity

Fig 3b. shows a G0, G1, and G2 surfaces created from corresponding curves in fig 3a. The 1<sup>st</sup> pair of G0 or positional continuity surfaces have a sharp seam at their patch borders. The 2<sup>nd</sup> G1 or tangential surfaces flow smoothly into one another and but may have visible seams. The G2 or curvature continuous surfaces flow smoothly into one another and appear seamless.

## Blend Curves

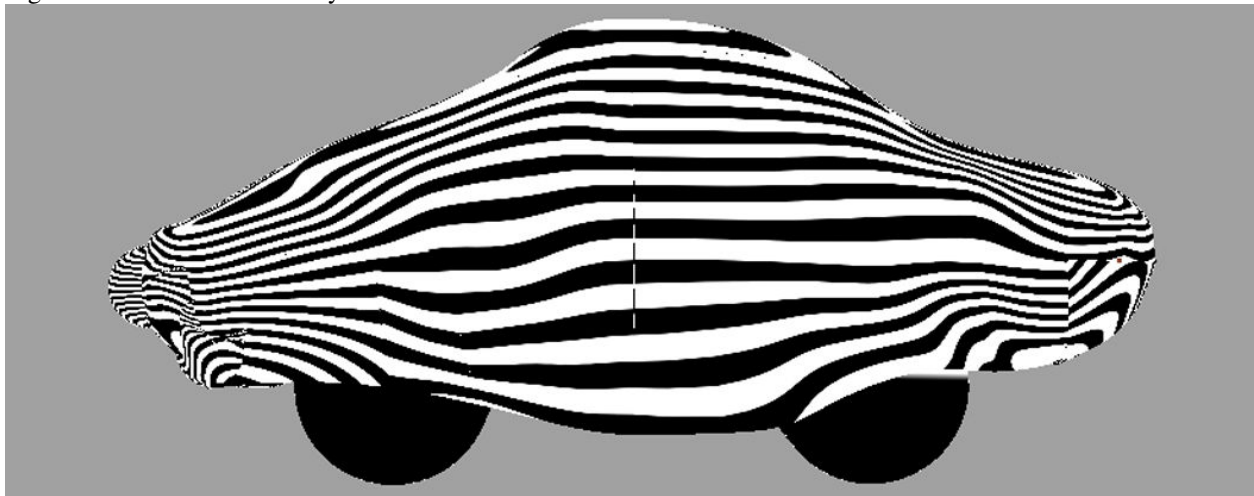
To assist the technical modeler in the creation of G2 curve networks, Studio Tools has a specialized set of curve creation tools called blend curves. Blend curves are controlled by interactive handles at their end points, called blend points that enable the user to specify various types of curvature continuity. There are 3 types of blend points listed in the table below. With blend points, the user can create complex curve networks without manually positioning every cv. The blend curve network of a concept car, shown in Table 4b, shows blend points positioned at the edit points of NURBS Blend curves. These blend curves were used to create surface patches.

Fig 4. Blend Curves		force the curve to ...	Blend Curve Network
	Location, G0	pass through the curve's blend point.	
	Direction, G1	have a specific tangent direction at the point of the blend point.	
	Geometry, G2	pass through a point on a curve or and travel in a direction relative to that curve or surface.	

### Surface Curvature Analysis

To appear seamless to the eye, multiple surface patches need to be curvature continuous across their edges. When manufactured these surface patches may form single part surfaces that should feel even and smooth to the touch of hands and fingers. Bumps will create multiple sharp, dull, or deformed specular highlights when digitally rendered. To diagnose seams and surface smoothness it is best to use the zebra stripe visual surface analysis shader. When a black or white stripe flows across G0 and G1 surface patches edges, the stripe will visually break, tear off or deviate at a sharp 90° angle. Smooth curvature continuous surface patches will have stripes that flow smoothly across patch edges. Fig 5. shows zebra stripes flowing smoothly across multiple patches. The visual break in the center of the car visually shows a seam at the door of the car. The break in the zebra stripe and the right rear end of the car shows a patch that needs rebuilding.

Fig 5. Surface Curvature Analysis

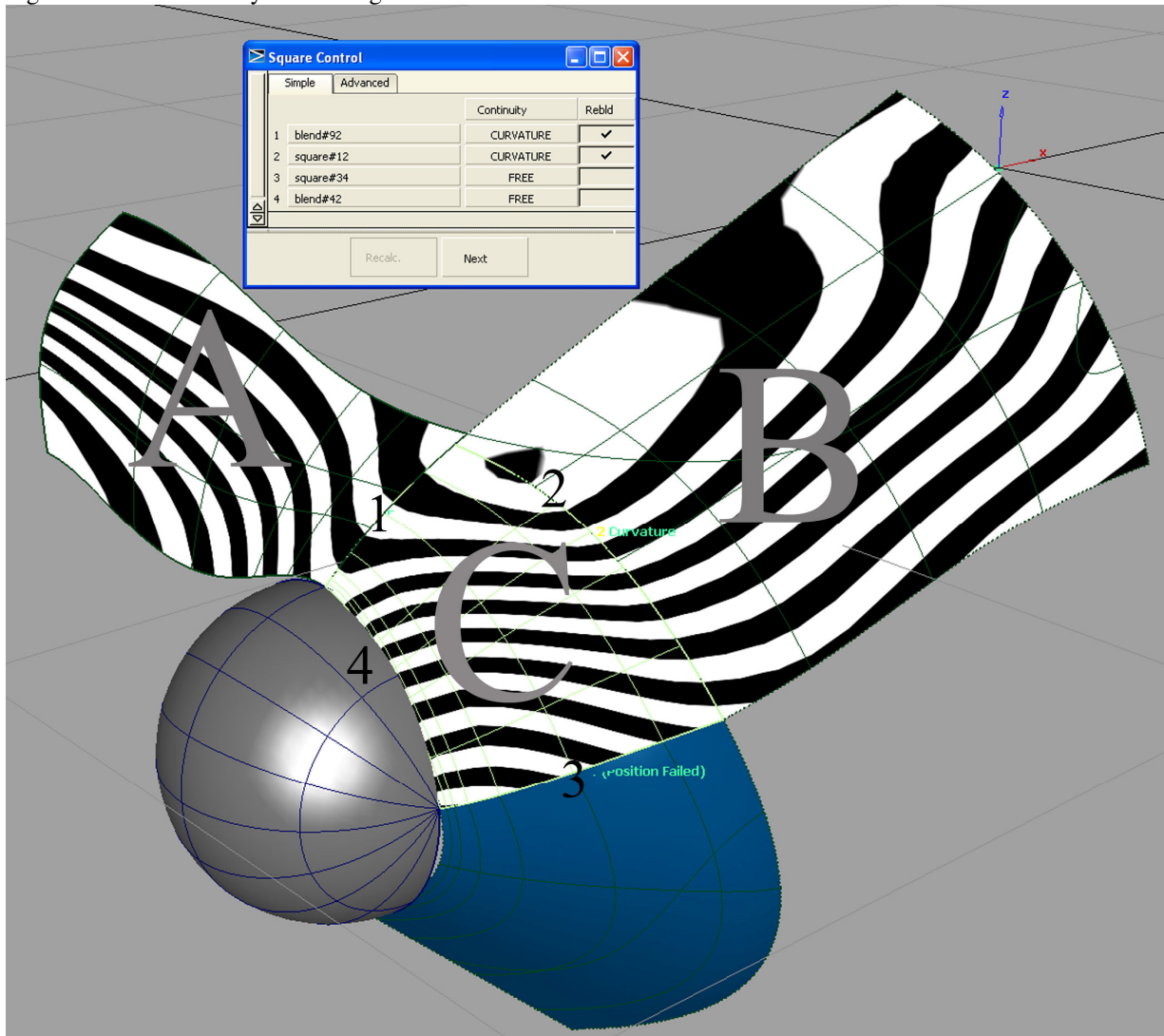


### Surface Rebuilding

Often the type of surface and/or order of curve selection do not produce smooth, seamless results. Manual and automated surface rebuilding practices are often necessary after doing surface analysis. The surface creation tools in Studio Tools have manual settings which enable users to specify the type of desired curvature for the sides of the intended surface.

When defining the continuity of surface patches, it is best to create surface patches in a logical order. In the example in fig 6, surfaces A and B were created before C. Note that both A and B touch patch C at its C's edges labeled 1 and 2. Note, when A and B were built the continuity on these shared edges was set to Free. To build patch C, the surface edges of A and B were selected and NURBS curves selected at edges 3 and 4. Selecting surface edges enables the surface tool to base it's continuity off a 3D surface, in this case patches A and B. To set the desired continuity for patch C, the square surface edit box was opened. C's edges 1 and 2 were set to curvature, edges 3 and 4 were set to free. This freedom enables the surface tool to position the patch C's surface cv's and achieve surface curvature continuity at edges 1 and 2. The results are zebra stripes that smoothly flow across edges 1 and 2 and seamless edges between surface A,B, and C.

Fig 6. Surface Continuity Rebuilding



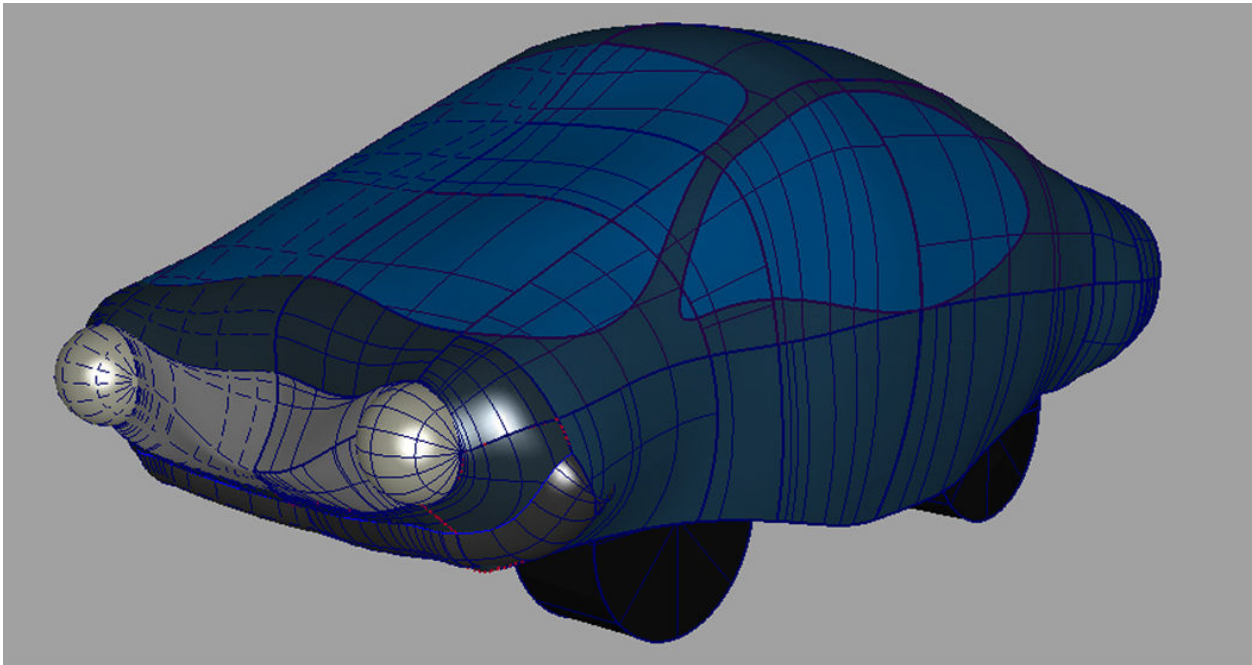
### Surface Refinement

Often this approach requires the user to remake the surface with different surface tools and/or to rebuild the surface by selecting surfaces in a different order. This trial and error approach means that user must 1<sup>st</sup> create the surface, analyze it's flow, and rebuild to improve the results.



## Conclusions

The goal of technical NURBS surface modeling is to create efficient curve networks and smooth surface patches surfaces that flow smoothly into one another so that they appear seamless. The curve and surface theories presented in this paper and practical continuity tools such as blend curves go along way toward achieving seamless results. Of course, experience building many types of models enables the user to achieve desired results with a greater degree of predictability. As a result achieving efficient, seamless, curvature continuous surfaces is both an art form and technical science. To improve and correct rough surface patches and distorted zebra stripes requires the user to closely examine the surface, and then rethink, and if needed redirect the modeling approach. To achieve desired end results, surfaces typically have to be built in different ways such as by: selecting surface edges and creation curves in a different order, using different surface tools, and by rebuilding surfaces. Even when the curve networks are constructed with proper curvature continuity often the desired surface continuity will fail. This complexity requires the technical modeler to think out of the box and experiment with the available tools.



## Bibliography

1. Alias Systems (2004) NURBS Modeling. Alias Toronto, Canada
2. Alias Systems (2004) Polygon Modeling. Alias Toronto, Canada
3. Alias Systems (2004) Subdivision Surface Modeling. Alias Toronto, Canada