International Journal of Mechanical Engineering and Robotics Research

ISSN 2278 – 0149 www.ijmerr.com
Vol. 3, No. 2, April 2014

Research Paper

AN OVERVIEW OF FLAT PATTERN DEVELOPMENT (FPD) METHODOLOGIES USED IN BLANK DEVELOPMENT OF SHEET METAL COMPONENTS OF AIRCRAFT

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Technological advances in sheet metal Computer-Aided Design and Computer-Aided Manufacturing (CAD/CAM) reveal a unique imbalance. Current thinking calls for more emphasis on especially for aircraft Sheet Metal Components (SMCs). Pioneering systematic research on practical methods of FPD together with efficient and accurate processing options has been created by authors and these developments have been reported with review of methods and systems. Loft or Ruled surfaces are especially developable surfaces are well-known and widely used in computer aided design and manufacture. This paper focus on review of developable surface, ruling and geometry of developable surface, its Coplanarity condition and also techniques of its Flat pattern development and blank shape prediction of SMCs.

Keywords: CAD/CAM, Flat Pattern Development (FDP), Sheet Metal Components (SMCs)

NOMENCLATURE OF FPD OF SHEET METAL COMPONENTS (SMCS)

Angle of Bend: The angle included between inward normal of bent and unbent surface.

Bend Correction (BC): The correction needed to be applied to true length of the cross-section of SMC surface model, in order to obtain the bend corrected length of the corresponding plane unbent sheet.

Flat Pattern (FP): It is the planar drawing of the blank required to form the desired sheet metal component.

Flat Pattern Development (FPD): It is the process of determining flat pattern for a sheet metal component corresponding to its neutral surface. The neutral surface is the surface within the sheet that is parallel to the inner and outer surfaces and on which the net stress of the sheet is zero.

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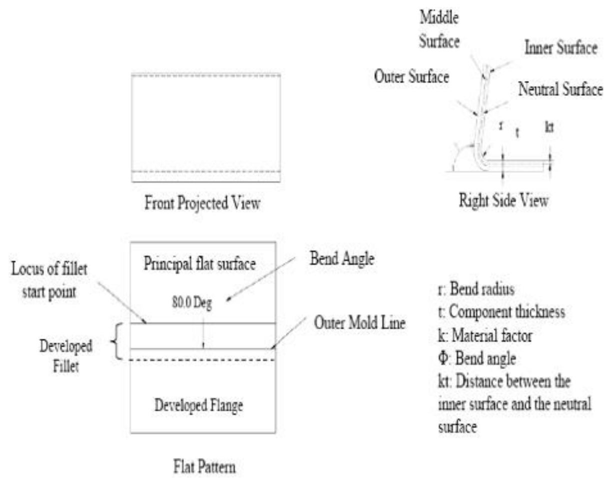
Principal Flat Surface (PFS): The principal flat surface is a planar surface (Z = constant), and this is the part of sheet metal component surface, which is held intact during the forming process.

OML: It defines the outer contours of airframe components and is used for making check templates for checking the formed components.

FLANGE: A flange is a (plane/curved) surface, part of SMC, which is attached to an Edge of the PFS with a connecting fillet and is produced by bending Sheet along the edge contour.

Figure 1: Flat Pattern Development of a Simple Sheet Metal



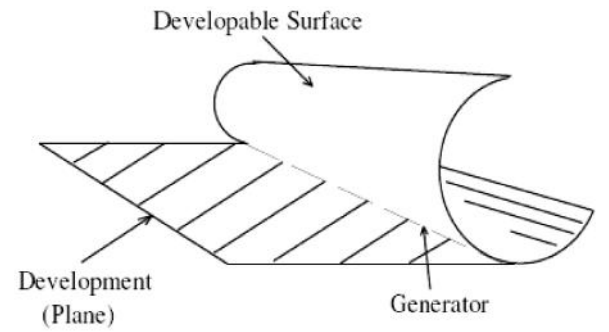
Source: Prasad and Selvaraj (2005) and Prasad et al. (2006)

DEVELOPABLE SURFACES

Introduction

The Shorter Oxford Dictionary defines a developable surface as "a ruled surface in which consecutive generators intersect". The Encyclopedic Dictionary of Mathematics for Engineers (Sneddon, 1976) defines a ruled surface as "a surface that can be generated by moving a straight line with one degree of freedom". This is shown in Figure 2, which also shows the developable surface being 'unwrapped' to form its development. The various positions of the line, moved with one degree of freedom, identify the "generators". Thus a developable surface or developable is a ruled surface with generators that intersect either at a point or intersect and are tangent to some arbitrary curve. This intersection point or curve is known as the edge of regression. Thus a developable surface is the surface described by a series of lines tangent to the edge of regression (Aumann, 2003). As it is well known, Struik (1961) and Postnikov (1979), developable surfaces may be classified into planar, cylindrical, conical and tangent surfaces. Whereas the first three types are easy to implement as Bezier and B-spline surfaces, the latter one is a bit more complex. Therefore they are of particular interest in the modeling of surfaces of approximately unstretchable materials, such as paper, leather or thin sheets of metal (e.g., Mancewicz and Frey, 1992). Even in the design and engineering of double curved ship surfaces developable surfaces appear in an important intermediate stage of the manufacturing process (Randrup, 1996; and Aumann, 2003).

Figure 2: A Developable Surface Showing the Plane Development Being Unwrapped from the Surface



Common developable surfaces have simple edges of regression. The two most common developable surfaces are the cone and the cylinder. The cone has an edge of regression at its vertex. This means that the generators that form a cone have the vertex of the cone as their origin. The cylinder has an edge of regression at infinity because the generators are parallel.

Development

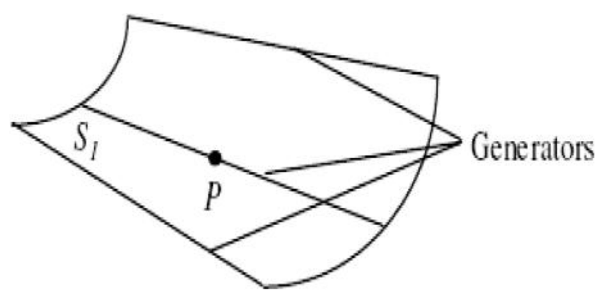
A development of a developable surface is formed when a developable surface is unwrapped onto a flat plane. In the process of unwrapping generator length and arrangement is preserved. The arc distance between two points on a developable is also conserved in the development. Because a development is flat its curvature in any direction is zero (Richard Geoffrey Templer, 1994; and Cohen-Or and Slavík, 2007). For a surface to be developable it must be capable of being unbent into a plane; i.e., a developable surface can only be deformed by bending about its generators. A cone may be unbent to form a segment of a circle and the radius of the circle will be the slant height of the cone. This is the development of a cone. Likewise the development of a cylinder is a rectangle with one side equal to the length of the cylinder and the other side equal to the circumference.

Geometry of a Developable Surface

A point on a general developable surface is shown in Figure 3. A general developable surface consists of a series of generators that originate from an edge of regression.

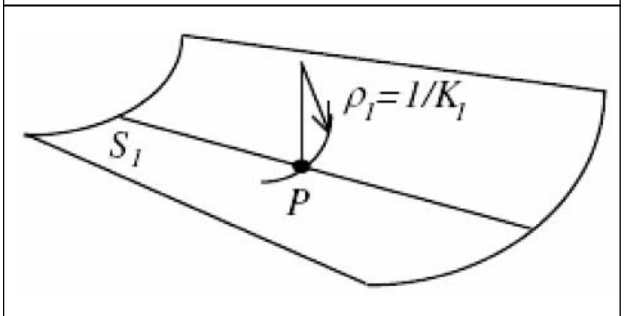
The curvature of a surface is a measure of the rate of change of the slope of a surface with respect to the distance across the surface. It is a property of developable surfaces that in the direction of the generators the curvature is zero. Because generators are straight lines their slope does not change along their length (Richard Geoffrey Templer, 1994). However, perpendicular to the generators, the curvature of the developable surface is at a maximum. This curvature is known as the principal curvature and is shown in Figure 4.

Figure 3: The General Developable Surface



Source: Richard Geoffrey Templer (1994)

Figure 4: The General Developable Surface with Maximum Principle Curvature K1 at P



Source: Richard Geoffrey Templer (1994)

Note that,

$$\rho_1 = \frac{1}{K_1}$$

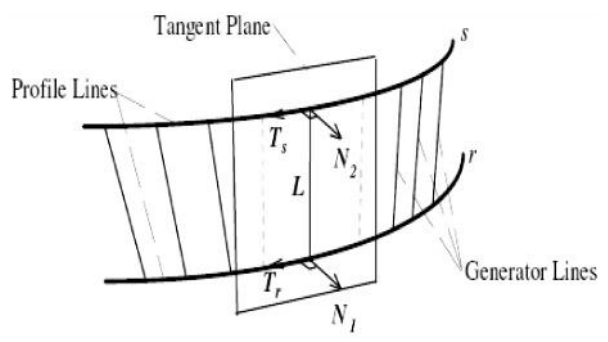
where, ρ_1 is the principal radius of curvature

Thus the developable surface at point *P* curves with a radius perpendicular to the generator of °$_1$. A common simple developable surface is a cylinder; the radius of a cylinder is equal to the radius of curvature and is the reciprocal of the curvature.

Ruling of a Developable Surface

For the different tangent planes, *T*, to the surface that will also be tangent to the directrix lines *s* and *r* (see Figure 5). These planes will be tangent along a line *L* contained in the surface and these lines are the generators or rulings. As a consequence, the normal vectors n_1 and n_2 at the endpoints of a ruling will be parallel. The conditions that the vector of a ruling *L* must satisfy can be described vectorially and can be expressed from the definition of the cross-product (Richard Geoffrey Templer, 1994).

Figure 5: Ruling of a Developable Surface



Source: Richard Geoffrey Templer (1994)

The normal to the generator lines may be calculated from:

$$N_1 = \frac{dr}{dx}(xi) \times Li$$

$$N_2 = \frac{ds}{dx}(xj) \times Li \qquad \ldots(1)$$

If N_1 and N_2 are parallel, *L* will be a ruling of the surface and this is satisfied when:

$$N_1 \times N_2 = 0$$

$$N_1 \cdot N_2 = 1$$

The module or length of the vector in above Equation can be written as

$$|N_1 \times N_2| = |N_1| \cdot |N_2| \cdot \sin(\Phi)$$

and working with unitary vectors,

$$|N_1 \times N_2| = \sin(\Phi) \qquad \ldots(2)$$

where, Φ is called the warp angle.

This angle has a physical significance that is of interest. It is the angle that the tangent plane must warp in order to be tangent to both directrix lines (Richard Geoffrey Templer, 1994).

Coplanarity Condition for Developability

Developable surfaces are a special case of ruled surfaces with null Gaussian curvature. This means that they are intrinsically flat. These are regions of planes that have been folded, rolled or pasted forming cylinders, cones in three-dimensional space, but without stretching them. They can therefore be extended back onto the plane without stretching them, at most by performing some cuts. (Cohen-Or and Slavík, 2007; and Fernandez-Jambrina and Navales, 2007)

If a surface is parameterized by *c*(*u*, *v*), with a normal vector *n*(*u*, *v*), the null Gaussian curvature condition may be expressed as:

$$0 = \begin{bmatrix} Cuu \cdot n & Cuv \cdot n \\ Cuv \cdot n & Cvv \cdot n \end{bmatrix}_{(u,v)} \qquad \ldots(3)$$

And in the case of a ruled surface generated by two curves, *c*(*u*) and *d*(*u*),

$$c(u,v) = (1-v)\,c(u) + vd(u)$$

the condition becomes much simpler,

$$cuv(u,v) \cdot cu(u,v) \times cv(u,v) = 0$$

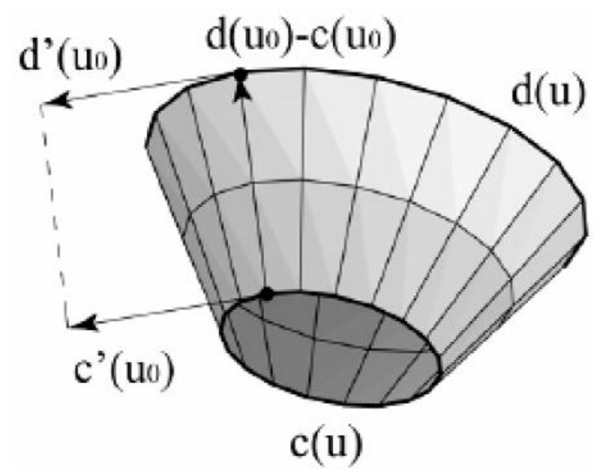
By either applying it to the curve $c(u)$, $v = 0$, or to $d(u)$, $v = 1$, the condition is further

Simplified,

$$d'(u) \cdot c'(u) \times \{d(u) - c(u)\} = 0 \qquad \ldots(4)$$

It has a direct general meaning. Since it states that the generators of the curves at u, $c'(u)$, $d'(u)$ and the vector that links the points $c(u)$, $d(u)$ are coplanar for a developable surface, as it is shown in Figure 6 (Aumann, 2003). Another way of looking at it arises by taking into account that if $c(u)$, $d(u)$, $d(u) - c(u)$ lie on the same plane for u, then $cu(u, v)$ and $cv(u, v)$ generate the same plane for u for all v. Therefore the tangent plane to the surface is the same for all points on the same line of the ruling and developable surfaces may be viewed as envelopes of uniparametric families of planes.

Figure 6: Coplanarity Condition for Developable Surface



Source: Fernandez-Jambrina and Navales (2007)

For Planar Surface

If all vectors lie on the same constant plane, that is, if $c(u)$ is a plane curve and $c(u)$ is a vector on the same plane for all u, we are depicting a region of the plane.

Representing planar surfaces is easy, since we just need a control net confined into a plane.

For Cylindrical Surfaces

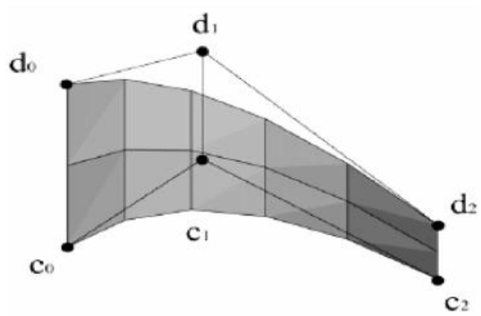
If $c'(u) \parallel c(u)$, the vector $c(u)$ is always parallel to a constant direction v,

$$d(u) = c(u) + {}^{a}(u)v,$$

$$c(u, v) = c(u) + {}^{a}(u)vv,$$

i.e., all the lines of the ruling are parallel. This provides an easy way to construct Bezier or spline cylindrical surfaces.

Figure 7: Cylindrical Bezier Surface

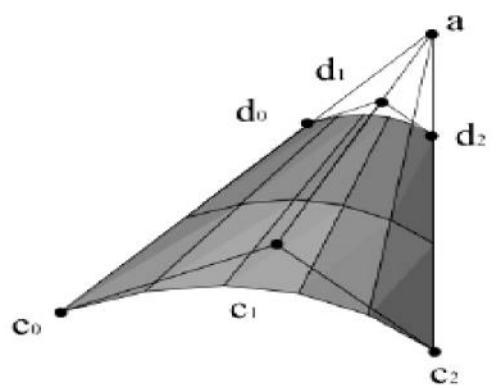


Source: Fernandez-Jambrina and Navales (2007)

For Conical Surfaces

$c'(u) = kc'(u)$, that is $c(u) = a + kc(u)$ and $d(u) = a + (k + 1)\, c(u)$, where a is a fixed point, the

Figure 8: Conical Bezier Surface



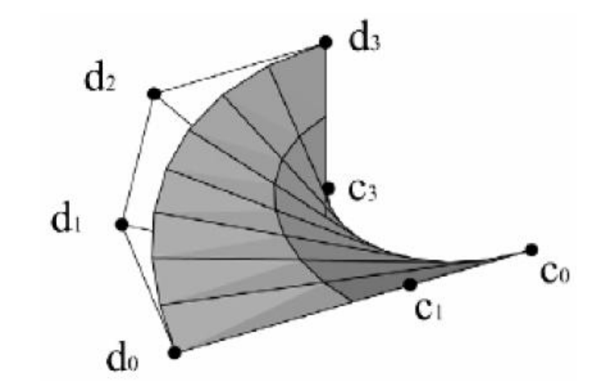
Source: Fernandez-Jambrina and Navales (2007) vertex of the cone, and every line of the ruling passes through it: $c(u, v) = a + (v + k)\ c(u)$.

For Tangent Surfaces

The line of the ruling at $c(u)$ is tangent to the curve at $c(u)$. The surface is therefore spanned by segments of the tangent lines to the curve $c(u)$. An example is shown in Figure 9.

$$c(u, v) = c(u) + v^a(u)\ c'(u).$$

Figure 9: Tangent Bezier Surface



Source: Fernandez-Jambrina and Navales (2007)

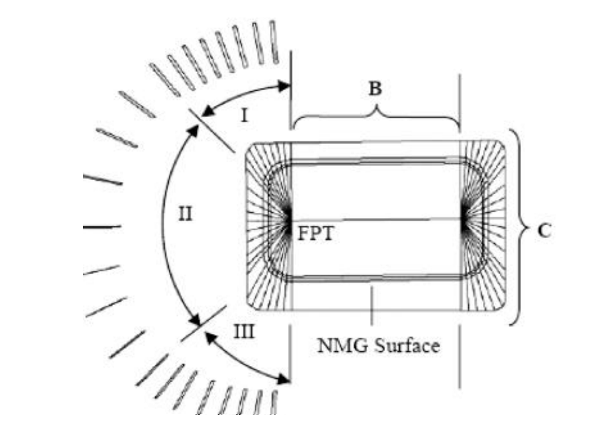
FLAT PATTERN DEVELOPMENT

A sheet metal component has significant thickness. The material factor '*k*' and the component thickness are important parameters in determining the flat pattern. Many different methods are conceived and researched to evolve suitable techniques. Some of these techniques are summarized in the following sections. These are basically transitional adaptations of sectioning techniques, which were successfully utilized for FPD of PFS class of SMCs.

Radial Sectioning

Radial sectioning is a method of making angular divisions on a surface. This is most suitable for fully curved SMCs with low radius of curvature bounding curves as well as for axi-symmetric components. Appropriate number of divisions is made based on geometry of the surface.

Figure 10: Radial Sectioning Method



Source: Prasad et al. (2006)

Limitations

- The user should identify the focal point in the CAD model interactively.
- Surfaces should be independent and discrete entities to apply radial sections.
- To plot angular lines, reference planes are required.

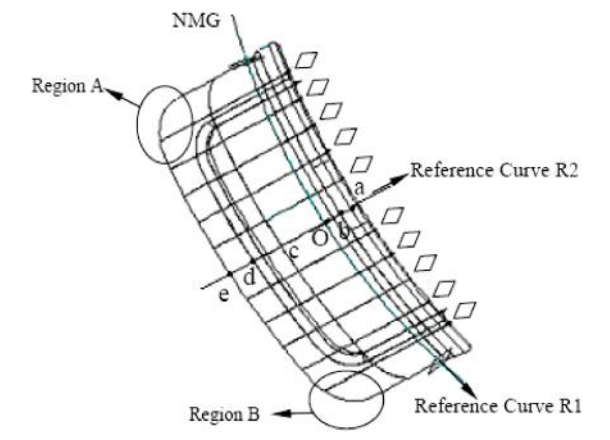
Parallel Sectioning

Parallel sectioning technique is another method of FPD process. The procedure is an adaptation of the CSD (Cross Section Development) method. Here the limitation of this technique lies in choosing the number of sections in regions such as A and B which need very high number of sections, yet with no guarantee for accurate FP determination.

Ortho-Normal Sectioning

This is another method of FP development wherein the given component is sectioned by sets of parallel planes normal to both reference

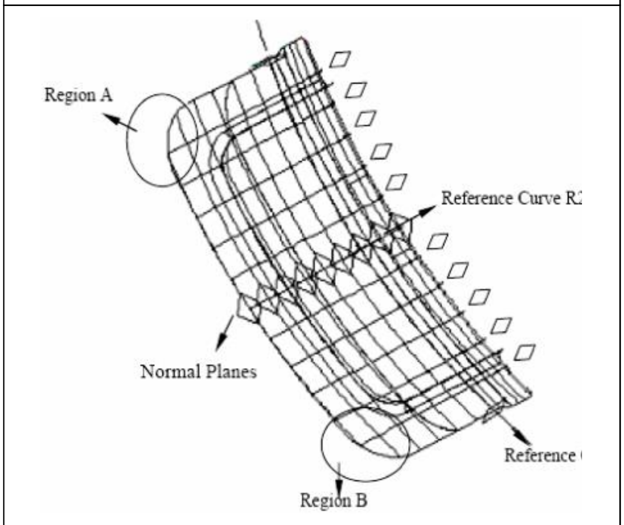
Figure11: Parallel Sectioning Method



Source: Prasad *et al.* (2006)

axes respectively. This is ideally suited for rectangular type of components; however, its limitations for general components are significant. Thus, this method is found to be efficient for a specific set of components while the same are highly inefficient for the rest. Thus, these developments could not result in a unique, reliable and efficient technique suitable for all the categories of general Non-PFS SMCs.

Figure 12: Ortho-Normal Sectioning Method



Source: Prasad *et al.* (2006)

Limitations

- Region A and B shown in Figure 12 require more sections.
- In these regions, interpolations would be needed as it might not be possible to obtain required intersections without unduly increasing the divisions.
- Sorting of these intersection points is tedious, time consuming and hence inefficient.

Apex Edge System

The apex edge system is designed to developed flat pattern for non-PFS components. Apex edge is a curve passing through the (central) apexes of its cross-sections, having shape similar to angles with either planar or non-planar (curved) flanges. This system is designed for a class of components having surfaces with some variations in curvature.

BLANK SHAPE PREDICTION

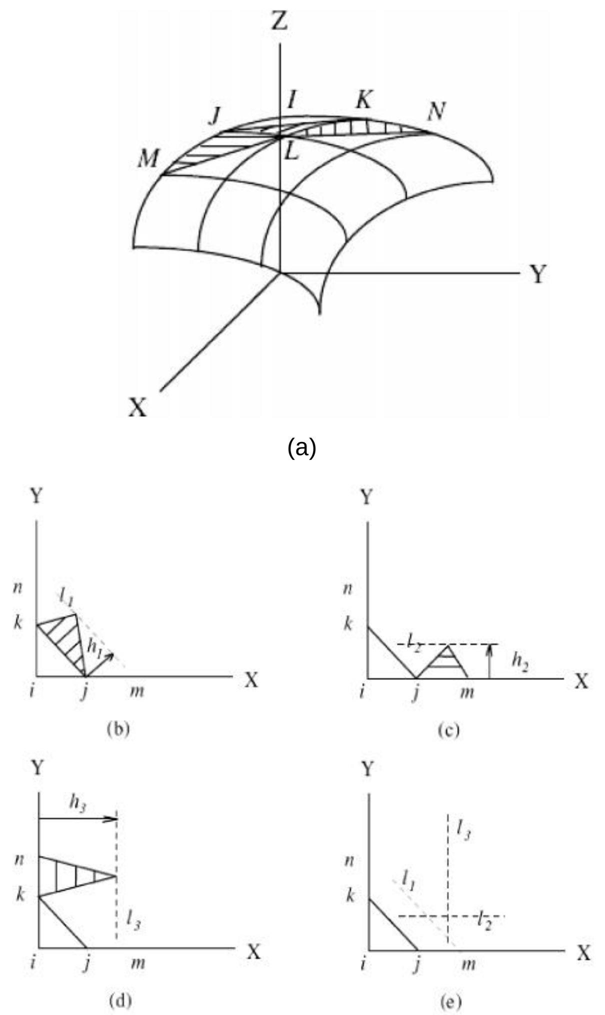
Computer Aided Blank Shape Prediction is a computer modelling method that can be used to predict blank shape. It is a geometric transformation based on an assumption of constant area. Previous work by Duncan *et al.* (1986) detailed a method of constant area transformation; this has been used to develop a computer modelling package. Computer Aided Blank Shape Prediction may be considered in two parts:

- Element Transformation and
- Boundary Specification

Element Transformation

The constant area transformation is a method of transforming the elements of a deformed surface onto a flat blank. Each element is assumed to deform without change in thickness or area (plane strain conditions) and continuity between elements is assumed so that there are no gaps or overlap. This can be drawn on the part or be generated by a computer mesh generation system. The nodes of the grid are then digitized and when these co-ordinates are known, geometric calculations and transformations can be carried out (Richard Geoffrey Templer, 1994).

Figure 13: (a) Region of Mesh Located on the Surface of a Part, (b)-(e) Complete Mapping Procedure



Source: Richard Geoffrey Templer (1994)

Boundary Specification

The development of Computer Aided Blank Shape Prediction has been three fold,

- Investigation of new boundary definition methods,
- Developing methods of assessing mapping performance,
- Investigating possible forming information obtainable from mapping (Richard Geoffrey Templer, 1994).

Right Side Length at 90° Method

Figure 14: Right Side Length at 90°

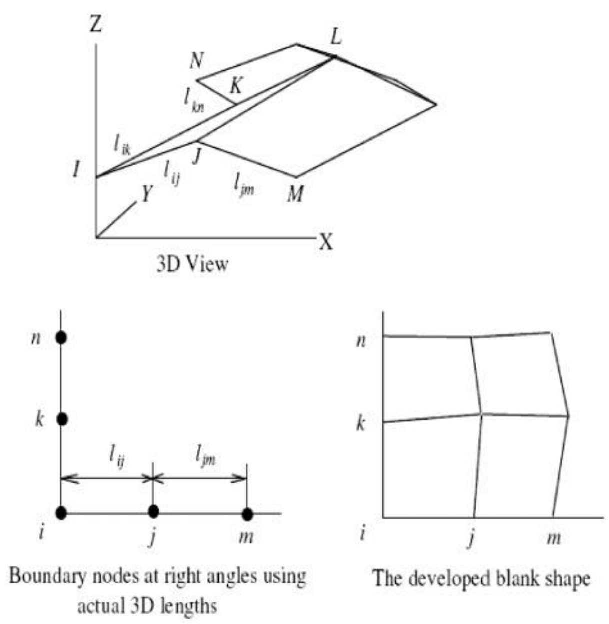
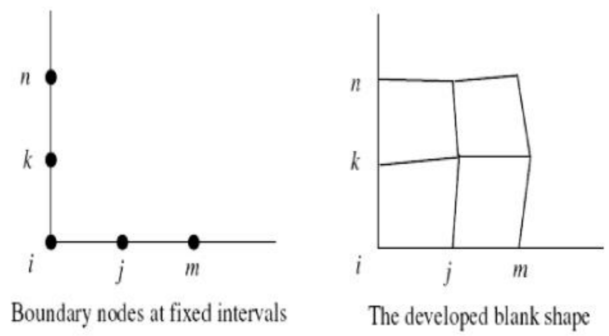
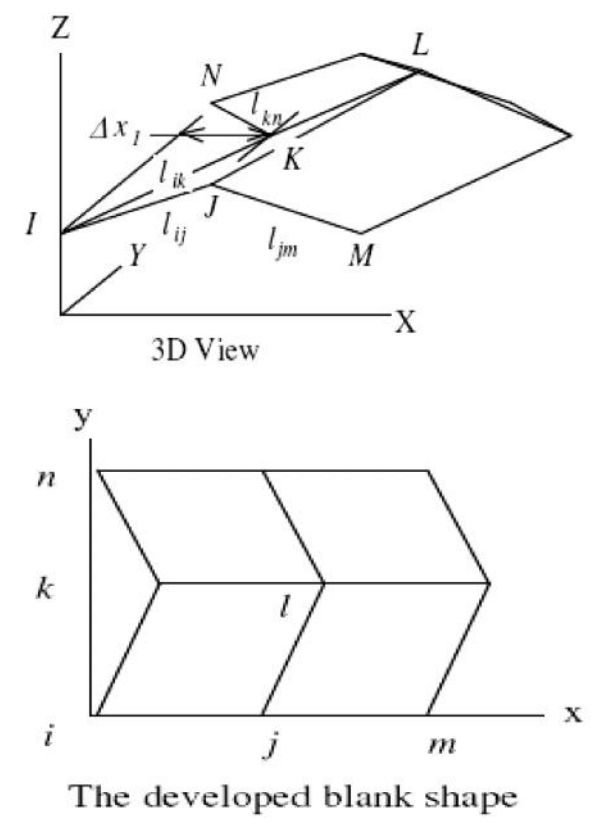


Figure 15: Actual Side Length at 90°



Curve Match Boundary Specification Method

Figure 16: Curve Match Boundary Method



Angle Conservation Boundary Method

Figure 17: Angle Conservation Boundary Method

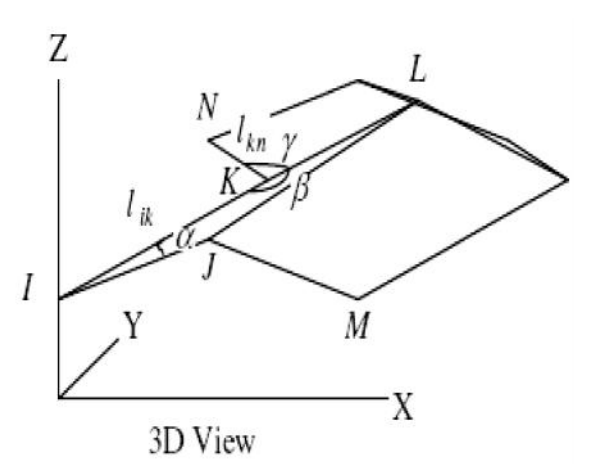
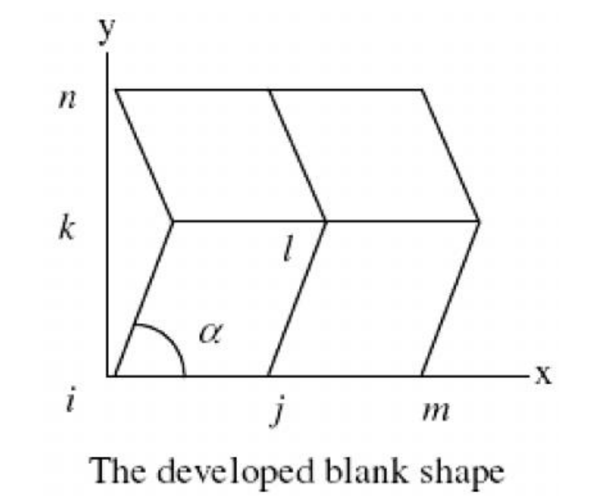


Figure 17 (Cont.)



The inclusion of these methods in a Computer Aided Blank Shape Prediction program increases both the accuracy of the prediction and the range of shapes that can be mapped (Richard Geoffrey Templer, 1994).

Area Ratio

A simple possible measure of the accuracy and correctness of the transformation can be found by comparing the areas of the three dimensional and two dimensional that make up the initial part and the final blank shape.

AR = Area of 3-D Developed Surface/Area of Flat Pattern

CONCLUSION

Ruled and Developable surfaces are widely used in Computer-Aided Design and Manufacturing (CAD/CAM) of sheet metal components. The review about various methods of flat pattern development of sheet metal components of aircraft are discussed here. This review helps for researcher to view different methodologies regarding Flat Patten Development for PFS and non-PFS types of sheet metal components of aircraft. Predicted reviewed methods are efficient for a specific set of components while some of could not be efficient technique suitable for all the categories of general Non-PFS SMCs. The area ratio defined for measure of the accuracy and correctness of flat pattern of blank shape.

REFERENCES

1. Aumann G (2003), "A Simple Algorithm for Designing Developable Bezier Surfaces", *Computer Aided Geometric Design*, Vol. 20, pp. 601-619.
2. Azariadisa P N and Aspragathos N A (1997), "Design of Plane Patterns of Doubly Curved Surfaces", *Computer Aided Design*, Vol. 29, No. 10, pp. 675-685.
3. Cohen-Or D and Slavík P (2007), "Geodesic-Controlled Developable Surfaces for Modeling Paper Bending", *Eurographics*, Vol. 26, No. 3.
4. Fernandez-Jambrina L and Navales E T S I (2007), "B-spline Control Nets for Developable Surfaces", *Computer Aided Geometric Design*, Vol. 24, pp. 189-199, Universidad Politecnica de Madrid, Arco de la Victoria s/n, E-28040-Madrid, Spain.
5. Helmut Pottmann and Johannes (1999), "Approximation Algorithms for Developable Surfaces", *Computer Aided Geometric Design*, Vol. 16, pp. 539-556, Wallner Institute for Geometric, 8-10 A-1040 Wien, Austria.
6. Julie Steele Chalfant (1997), "Analysis and Design of Developable Surface for Shipbuilding", June, Mechanical Engineering, United State Naval Academy, Department of Ocean Engineering and Department of Mechanical Engineering, Massachusetts Institute of Technology.
7. Meng Sun and Eugene Fiume (1996), "A Technique for Constructing Developable Surfaces", Department of Computer Science University of Toronto10 King's College Road Toronto, Canada.
8. Prasad K S R K and Selvaraj P (2005), "On the Considerations for the Design of an Automated Aircraft Sheet Metal Component Production Loft Generation System (PLGS)", *International Journal of Production Research*, Vol. 43, No. 14, pp. 3045-3067.
9. Prasad K S R K, Selvaraj P, Praveen V Ayachit and Nagamani B V (2006), "On the Development of Lofts for Doubly Curved Sheet Metal Components", *International Journal of CAD/CAM*, Vol. 6, No. 1, pp. 199-211.
10. Richard Geoffrey Templer (1994), "Computer Aided Modelling of Sheet Metal Forming", August, Ph.D Thesis, Department of Mechanical Engineer, The School of Engineering, University of Auckland.
11. Stefan Leopoldseder and Helmut Pottmann (2003), "Approximation of Developable Surfaces with Cone Spline Surfaces", December 31, Institute for Geometric Technical University at Wien, 8-10 A-1040 Wien, Austria.
12. Zha X F (1997), "A New Approach to Generation of Ruled Surfaces and its

Applications in Engineering", *International Journal of Advanced Manufacturing Technology*, pp. 155-163, School of Mechanical and Production Engineering, Nanyang Technological University, Nanyang Avenue, Singapore.