Free-Form Surfaces Design Using Reverse Engineering Depending on Cross-Sectional Design Method

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ABSTRACT

This research presented a strategy for designing a particular set of surfaces, obtained by the technique of cross-sectional design. The surfaces considered were formed by sliding a Bezier curve (profile curve), and also this research describes an automatic procedure for selective identification of sampling points in reverse engineering applications using Coordinate Measurement Machine.

In addition, Matlab program have been used in the present work so as to plot the curve sections of the surfaces using transformation matrices. UGS program have been also used to connect the sections that designed in Matlab program to get the final shape of the proposed surface. It can be concluded that the whole steps task which built in the present research can be programmed in a single block of the part program that's from it can be create any curve or surface at minimum designing time.

Keywords: Free-form surfaces, reverse engineering, UGS program.

1. INTRODUCTION

In the automobile, aerospace and appliances industry, a variety of functional or even aesthetic free-form surfaces are engaged by engineers and designers to achieve the desired performance of a product. The machining of such complex geometries is a basic problem in computer-aided manufacturing since the available NC machines are constrained, by their software, to linear and circular motions [1,2]. Also, from reverse engineering which is (a technique used during the project phase of a new product) can be depending on it to improve the design of any surfaces or it can be create a new surfaces depending on the original surface. Scientific literature presents many different approaches to reverse engineering. Great part of those are based on the analysis of point clouds acquired through coordinate measuring devices, such as, for example, Coordinate Measuring Machines (CMMs), Optical Scanners or interferometric systems [3].

Accordingly, there are different methods to generate the complex surfaces. General methods for determining the volume swept by a tool undergoing 5-axis motion, namely, envelope theory [4,5] and the SEDE algorithm (**S**weep **E**nvelope **D**ifferential **E**quation) [6], are computationally complex and difficult to implement. Vector methods offering an approximate approach generally fall into three classes: view based, z-map based or normal vector based. These methods are based on either envelope theory or the SEDE or are based on static instances of the tool at various locations and ignore the movement of the tool. While the tool movement can be approximated by using many instances of the tool at intermediately interpolated positions. Also, voluminous part programs with these motions are generated by computer aided design (CAD) systems, driving the cutting tool through a set of points approximating the complex paths [7, 8 & 9]. Inevitably, the continuous succession of accelerations and decelerations of the driving motors causes feed rate variations, decreases machining accuracy and requires more machining time. However, in many cases the design of a surface does not require a grid of control points as is the case of general free-form surfaces. The design of these surfaces fit into a special technique named *cross-sectional design* method.

In general, the cross-sectional design technique requires one or more profile curves that describe the profile, or cross-section, of the desired surface and perhaps a trajectory curve that guides that way of sliding the profile curve. As the profile curves slide along the trajectory curve, a surface is generated [2].

Accordingly, the present research, following the present intention of research engineers to take advantage of the hardware capabilities of modern CNC systems, proposes a real-time surface interpolator for machining the specified surfaces on CNC milling machine. Where, Bezier curves will be used to define the shapes of the curve profile. Bezier curve as free-form curves is a powerful designing tool. It's need only a few points to define a large number of shapes, hence their wide use in CAD systems. Despite the particularity in the definition and the design of these surfaces, the available CAM systems deal with them as with free-form surfaces. Consequently, the transformation matrices in Matlab program will be utilized in the present research to design the proposed surface.

2. CROSS-SECTIONAL DESIGN CONCEPT WITH BEZIER CURVES

Surface of revolution in the present work will be produced using the method of cross-sectional design concept. The surface is generated by revolving the designed curve about an axis. The designed curve is a profile curve while the axis is the axis of revolution and the curve of this axis is the trajectory curve, **Fig.(1)**.

To generalize Bezier's curve to n-degree, control points can be blended together depending on Bezier's equation as follow[10]:

$$r(u) = \sum_{i=0}^{n} B_{n,i}(u) p_i \qquad 0 \leq u \leq 1 \tag{1}$$

Where

$$B_{n,i}(u) = \frac{n!}{i!(n-i)!} u^i (1-u)^{n-i} \tag{2}$$

3. BLENDING BEZIER'S CURVE

Bezier's curve can be constructed by using another different scheme that is the blending one. The idea is based on blending a new Bezier's curve $r^2(u)$ between two existing Bezier's curves $r^1(u)$ and $r^3(u)$ to form a composite Bezier's curve.[9].**Fig.(2)** .

To ensure C^0 and C^1 continuity, the following equations must be guaranteed:

$$\left. \begin{array}{l} p_0^2 = p_3^1 \\ p_3^2 = p_0^3 \end{array} \right\} \tag{3}$$

4. UTILIZATION OF MATLAB PROGRAM

In the present work Matlab program have been used to plot the blending curves, and to get the sections of the surfaces using transformation matrices. The program of the surface design consist sub-programs depending on the number of transformation matrices that will be used in the present work, as follow:

a. Design the base section of the surface
At first, the base section of the surface will be designed and plotted using Bezier's equation and blending Bezier's equation, as shown in **Fig.(3)**.

b. Translate the blending Bezier's profile
    In this case, the translation matrix will be used, which is mean move objects with respect to their current locations, specify the translation as distances *tx*, *ty*, and *tz* in data space units. The following matrix shows the location of these elements in the transform matrix.

$$\text{Translating matrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ t_x & t_y & t_z & 1 \end{bmatrix} \tag{4}$$

Where, this mean the second section of the surface will be introduced, as shown in **Fig.(4)**.

c. Scalling the blending Bezier's profile
    The profile of the second section will be reduced in (*XY*) plane using scaling matrix:

$$\text{Scaling matrix} = \begin{bmatrix} S_x & 0 & 0 & 0 \\ 0 & S_y & 0 & 0 \\ 0 & 0 & S_z & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{5}$$

Where, *Sx*, *Sy* and *Sz* represent the reduce or enlargement magnitude, and after the scaling matrix used, the third section of the surface will be appear as displayed in **Fig.(5)**.

d. Translate the third section
    The translation matrix also will be used so as to translate the third section in Z-axis., as appeared in the **Fig.(6)**.

e. Rotating the blending Bezier's profile
    Finally, the profile of the third section will be rotate about *Z*-axis using rotatation matrix. Where rotation transforms matrix mean rotate objects about the *X, Y,* or *Z*-axis, with positive angles rotating counterclockwise while sighting along the respective axis toward the origin. If the desired angle of rotation is (θ), then the following matrices define this rotation about the Z- axis.

$$\text{Rotating matrix} = \begin{bmatrix} \cos(\theta) & \sin(\theta) & 0 & 0 \\ -\sin(\theta) & \cos(\theta) & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{6}$$

Where, this mean the fourth section of the surface will be introduced, as shown in **Fig.(7)**. Where, from the above sub-programs using transformation matrices, flow chart in **Fig.(8)**, can be explained the steps of the program that was built up to represent the shape of each section.

5. PROPOSED WORK (CASE STUDY)

The development of the aeronautic and automobile industries brought new complex surface that can be achieved, which related to the growing complexity of the products and the new geometries modeled in CAD systems. From these more complex geometries wing blade will be selected as a proposed problem in the present work so as to aperients the method of design it. Traditionally utilized methods of creating wing blade geometry in CAD systems can be lengthy and prone to human error. This process can range from hours to days using traditional 3D modeling techniques. The measurements of the sample wing blade was taken here using CMM for different sections, and then the data of the measurements in *X*, *Y* and *Z*-axis were saved to use it in design the sections in Matlab program. **Fig.(9 a, b and c)**, shows the sample of the wing blade that was machined and measured using multi-axis CNC milling machine and CMM respectively.

From **Fig.(9 a, b and c)**, Matlab program and UGS have been utilized as CAD/CAM tool to implement proposed work. Where Matlab program will be used to design the curves of the wing blade and blend these curves together using equations (1,2 and 3). Also, it will be taken in our consideration the flexibility in Matlab program, where the functions and transformation matrices will be utilized in the design program of the wing blade curves. As to the surface's creation, UGS will be used to create a surface between these sections that designed so as to reached the final shape of the wing blade. So, the present work divided into two divisions, as follows:

- **Create the sections of the curves using Matlab program**

The sections of the wing blade surface will be built using Bezier's equation and blending Bezier's equation as mentioned previously, also the transformation matrices will be utilized to modified the sections of the surface, as shown in **Fig.(10)**.

Where, **Fig.(10)** explained the following:

a. Shows the first section of the surface.

b. Shows the second section of the surface using translation matrix.

c. Shows the third section of the surface using rotation in *counterclockwise* direction and translation matrix.

d. Shows the fourth section of the surface using rotation in *counterclockwise* direction and translation matrix.

e. Shows the fifth section of the surface using rotation in *clockwise* direction and translation matrix.

f. Shows the sixth section of the surface using rotation in *clockwise* direction and translation matrix.

- **Create the surface of the sections using UGS program**:

Here, curves will be covered and connect the sections of the blade so as to create the final surface using UGS program, and also the analyzer options of UGS program will be used to get the final surface, as shown in **Fig.(11)**.

6.CONCLUSIONS

A strategy for designing a particular set of surfaces, obtained by the technique of cross-sectional design was presented in present work. The surfaces considered were formed by sliding a Bezier curve (profile curve). The curves were located in perpendicular planes. Also describes an automatic procedure for selective identification of sampling points in reverse engineering applications using CMM was presented. The methodology has been applied to different kind of free-form patterns. Looking at the obtained results, it is possible to say that this procedure has a good level of applicability in automated scansion systems. The use of

scanning device measurement uncertainty turns out a general purpose procedure for identification of critical zones without operator involvement.

The simulation results using UGS program of the designing processes indicate a significant time savings for the leading aerospace manufacturer when using the wing blade as opposed to the current modeling method.

7. REFERENCES

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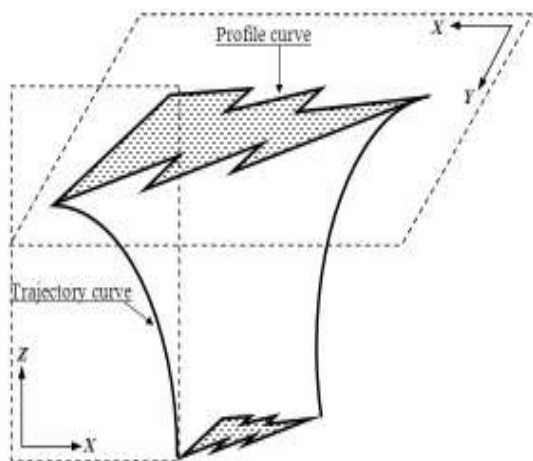
Figure (1): Cross-sectional design technique.
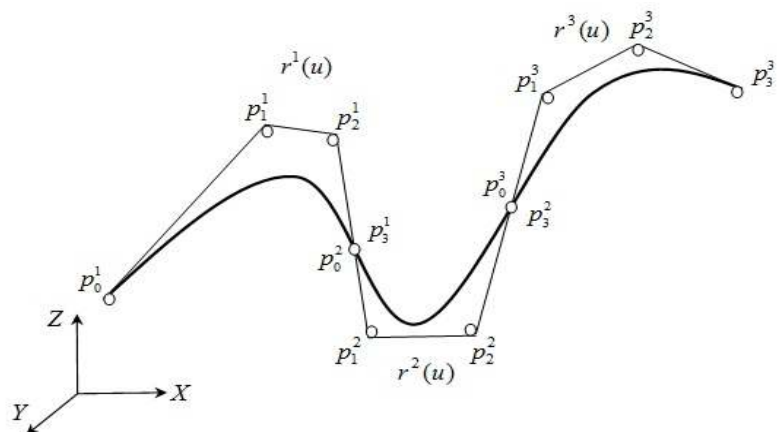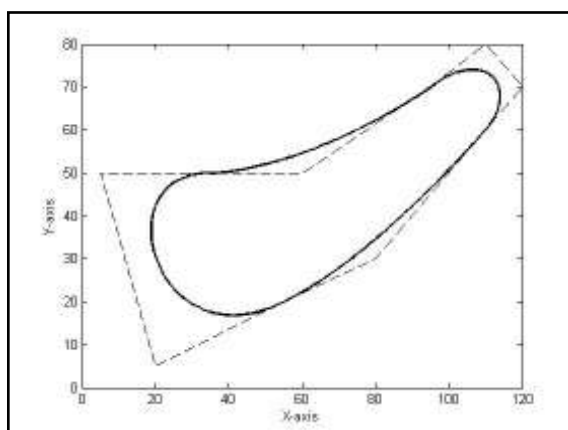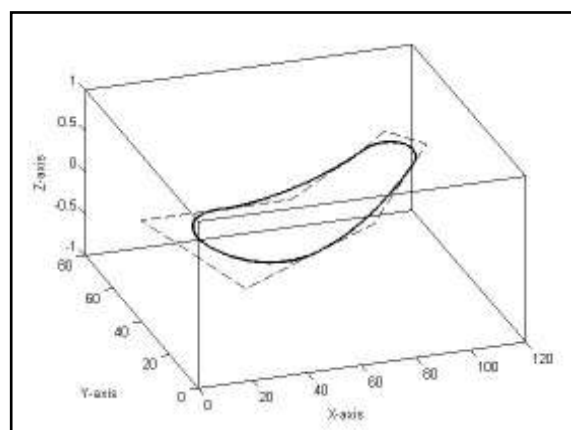
Figure (2): Blending Bezier's curve.

(a)

(b)

Figure (3): (a) surface base section design in top view, **(b)** surface base section design in isometric view.
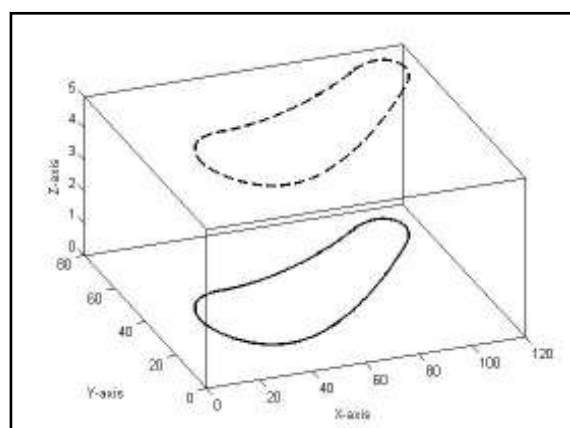
Figure (4): The first and second section of the surface.

(a)   **(b)**
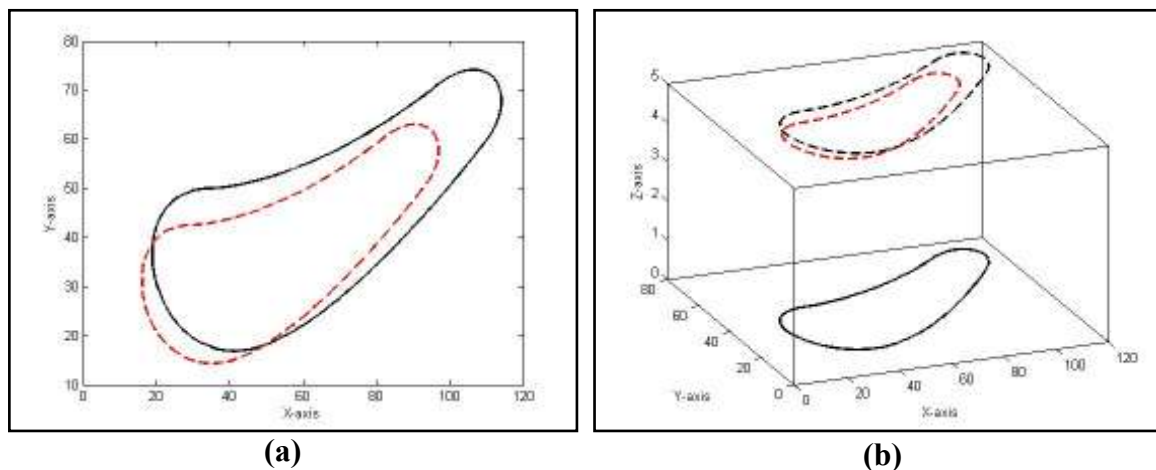
Figure (5): (a) scaling of blending Bezier's curves in top, **(b)** scaling of blending Bezier's curves in isometric view.

(a)   (b)
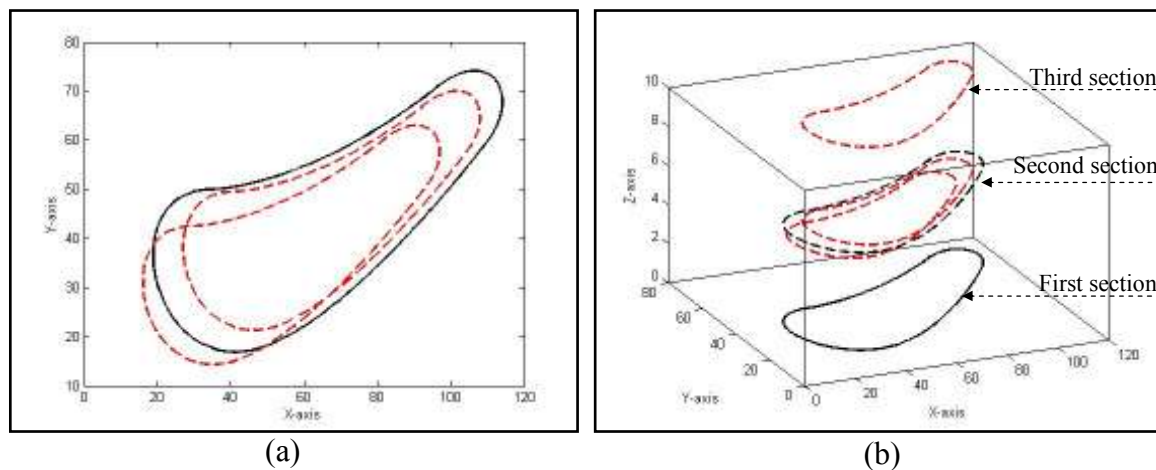
Figure (6): (a) the translate section of the surface in top view, **(b)** the translate section of the surface in isometric view.

(a)   (b)
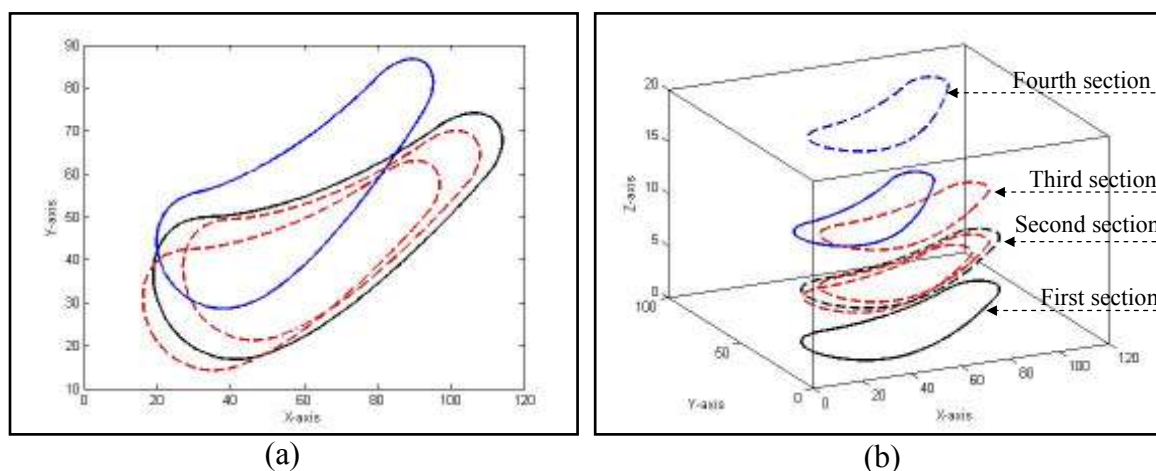
Figure (7): (a) the rotating of blending Bezier's curves in top view, **(b)** the rotating of blending Bezier's curves in isometric view
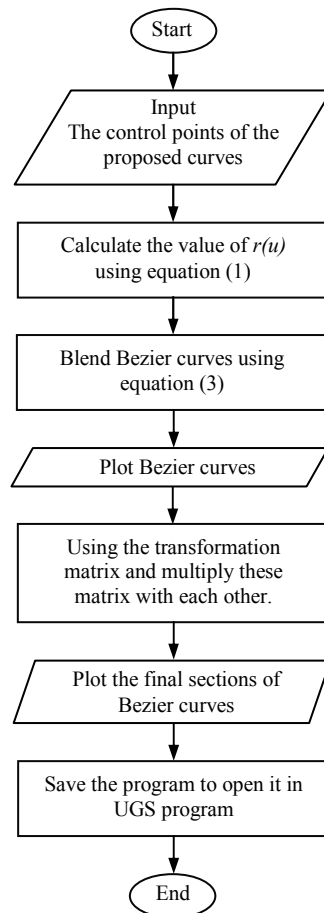
Figure (8): Flowchart of the program steps.

(a)   (b)   (c)

Figure (9 a, b and c): Appeared the front and side view for the wing blade sample's that was machined and measured using multi-axis CNC milling machine and CMM

(a) **(b)** **(c)**

(d) **(e)** **(f)**
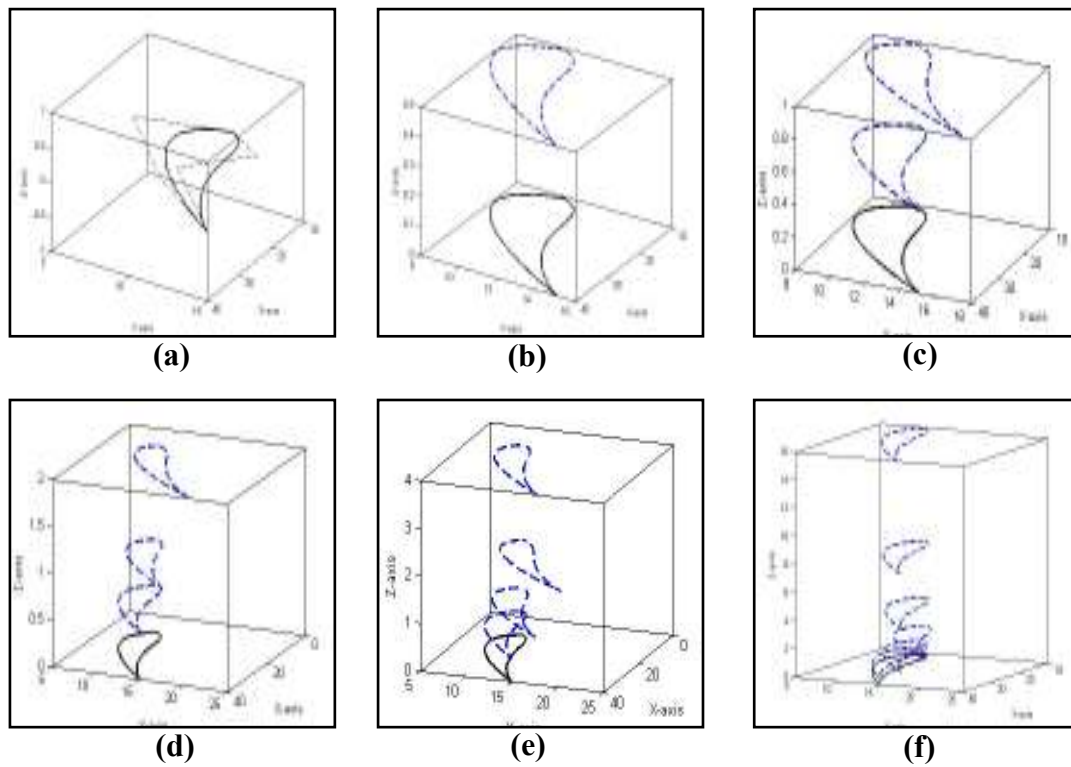
Figure (10): The sections of the wing blade surface.

(a) (b) (c) (d)
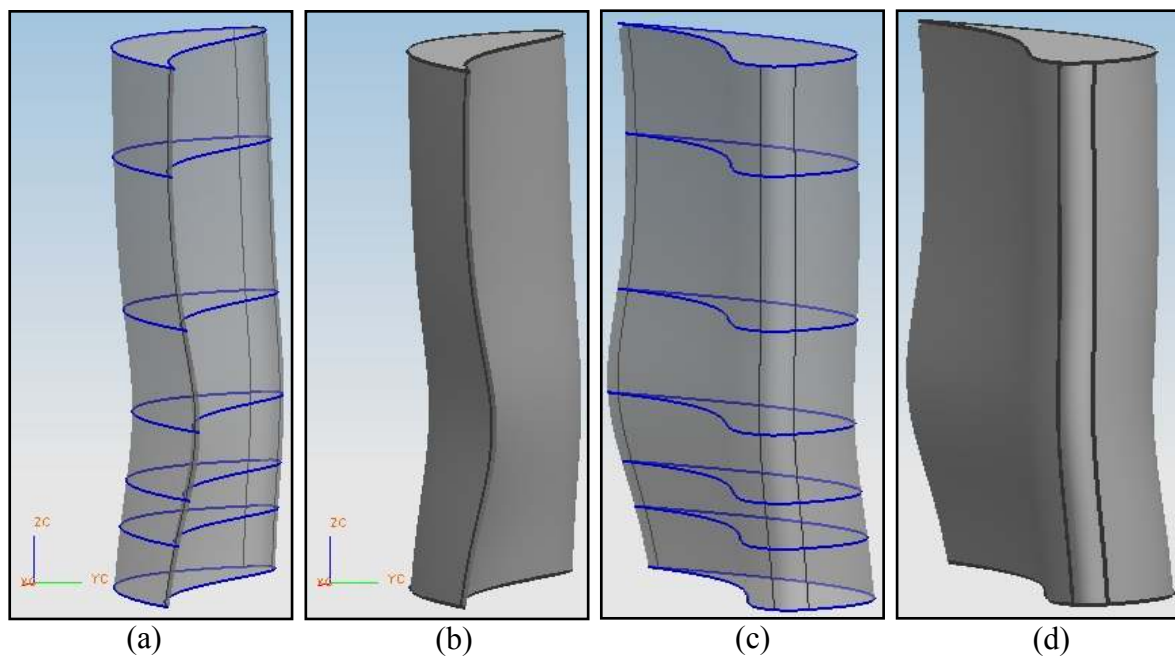
Figure (11 a, b, c and d): The surface of the wing blade that was created using UGS program with the sections of the curves.

تصميم الأسطـح الحـرة باستـخدام الـهـندسـة العكسيـة اعتمـاداً عـلى طريقة التصميـم للمــقاطع المستعـرضة

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الخلاصـة.

في هذا البحث تم بناء إستراتيجية لتصميم أجزاء معينة من السطوح من خلال استخدام طريقة التصميم للمقاطع المستعرضة، حيث يتم الحصول على تلك السطوح من خلال دمج المنحنيات التي استحدثت باستخدام معادلة بيزر لتوليد المنحنيات، إضافة إلى ذلك فان البحث الحالي يصف الطريقة المبرمجة لأخذ نقاط السطح الهندسي باستخدام الهندسة العكسية بالاعتماد على ماكنة قياس المحاور .

تم استخدام برنامج Matlab في العمل الحالي لرسم منحنى المقاطع للأسطح باستخدام مصفوفات التحول. كما استخدم برنامـج   UGS   لربط المقاطع التي تم تصميمها في برنامج Matlab للحصول على الشكل النهائي للسطح المقترح. نستنتج انه جميع الخطوات والبرامج التي تم بنائها في البحث الحالي يمكن برمجتها ببرنامج واحد يتم من خلالها استحداث أي منحي أو سطح بأقل وقت ممكن.