J. Marine Sci. Appl. (2012) 11: 453-461
DOI: 10.1007/s11804-012-1155-9

# Automatic Generation of the Planning Tunnel High Speed Craft Hull Form

**Morteza Ghassabzadeh and Hassan Ghassemi***

*Department of Ocean Engineering, Amirkabir University of Technology, Tehran 15875-4413, Iran*

**Abstract:** The creation of geometric model of a ship to determine the characteristics of hydrostatic and hydrodynamic, and also for structural design and equipments arrangement are so important in the ship design process. Planning tunnel high speed craft is one of the crafts in which, achievement to their top speed is more important. These crafts with the use of tunnel have the aero-hydrodynamics properties to diminish the resistance, good sea-keeping behavior, reduce slamming and avoid porpoising. Because of the existence of the tunnel, the hull form generation of these crafts is more complex and difficult. In this paper, it has attempted to provide a method based on geometry creation guidelines and with an entry of the least control and hull form adjustment parameters, to generate automatically the hull form of planning tunnel craft. At first, the equations of mathematical model are described and subsequent, three different models generated based on present method are compared and analyzed. Obviously, the generated model has more application in the early stages of design.

**Keywords:** planning tunnel craft; hull form; automatic generation; high speed craft
**Article ID:** 1671-9433(2012)04-0453-09

## 1 Introduction

Planning crafts are one of the three types of crafts: displacement, semi displacement and planning. Based on the definition, if the Froude number is more than 1.2, the craft is planning type. In another division, the crafts are divided into four categories based on the source of the lift force which is a combination of four types of forces: hydrodynamic, aerodynamic, aerostatics and hydrostatic. The lift force of planning crafts is provided by the hydrodynamic effects at maximum speed (operation conditions) and by the buoyancy effects at low speed. In the overall division based on the body form, advanced crafts are divided into four different categories as shown in Figure 1.

One type of the advanced crafts is the tunnel craft that efficient research scheme are scarce. These crafts are usually in planning crafts category according to speed characteristics. Based on the lift force, the tunnel craft is transited between 3 states; aerodynamics, hydrodynamics and hydrostatics. At last, according to the body form, these crafts are usually in multi-hull category. According to the operation of the planning tunnel craft, to need more quickness with less resistance, its hull form is more complicated and the accuracy in design of elements of the hull form is more important. Also, the optimization of the hull form in design process is one of the necessary steps which is costly and time consuming. Besides the numerical analysis or laboratory tests, generation and fairing of the hull form for its studying and analysis are a major step of the conceptual design stages. Because of this, accessing automatically the generation method of hull form based on the least entry parameters to control and adjusting the hull form is essential. So, this paper is attempted to provide a creative method for generating the hull form automatically in the conceptual design stage.

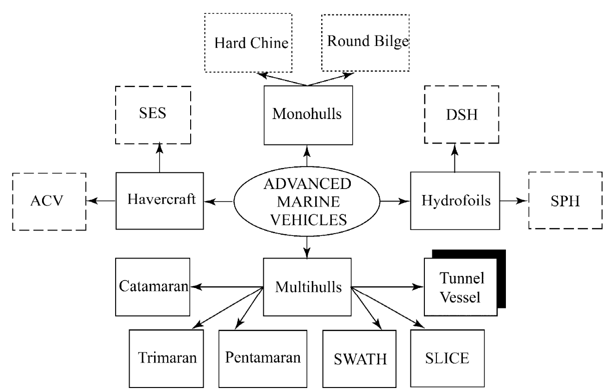


**Fig. 1 Types of the advanced marine vehicles based on the hull form**

For the planning and non-planning craft, some articles have been published during recent decade. Calkins *et al.* (2001) developed a tool for chined hull generation in concept design; this may help the designer during the early stage of the project. At any rate it requires the definition of several parameters and the three-dimensional hull fairing is not ensured. Hinatsu (2004) created a method to generate the surface of craft hull with the least parameters by use of the Fourier series and non-uniform B-Spline. A new fairing algorithm applied to the experiments of ship hull plate processing surface by Liu *et al.* (2005). Arribas *et al*. (2006) presented a method for the automatic generation of hull form of craft using of Spline curves. Mancuso (2006) published his

**Received date:** 2012-01-25.
***Corresponding author Email:**gasemi@aut.ac.ir

work about the parametric design of hull form of the sail boat by using the B-Spline surfaces. Also, a research creating a method for the optimization of smooth hull form of craft was presented by Sarioz (2006). The parametric generation of crafts geometry with curved bilge and fishing crafts based on the non-uniform B-Spline surfaces was reported by Hu *et al*. (2008) and Perez *et al* (2008).

As it can be seen in the reported researches, most of the works has been done about the creation of the hull form of the general ships and rarely has the subject of planning crafts hull form generation methods. It included mono-hull and catamaran planning crafts and did not include the hull form of planning tunnel crafts. This paper developed a computational automated method for defining the hull form of planning tunnel high speed craft in the conceptual design step.

## 2. Methodology

### 2.1 Planning tunnel craft

The body of tunnel crafts is composed of three general parts. The first part is the central displacement part which provides the maximum hydrostatics force and the tonnage increasing of crafts is significantly considered only on this part. The front of this part has been curved up in order to reduce the pressure force from air and water during the craft speed increasing. The second part is a planning tunnel which creates the hydrodynamic and aerostatic lift forces with imprisonment of air and breast waves. Finally, the third part is a rigid edge on the outer positions of tunnels which is used for continuous air imprisonment, air escape prevention and the breast waves.

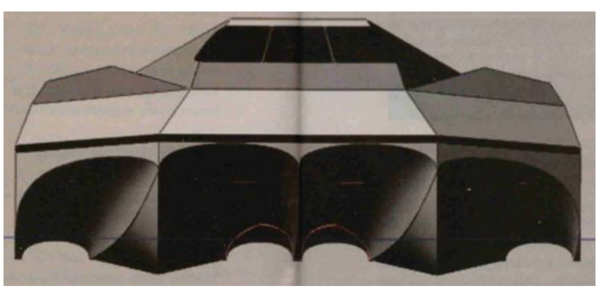

**Fig. 2 Scheme of body form of the tunnel craft**

Fig. 2 is an example of the body form of a tunnel craft. It is obvious that the combinations of these three parts together in the more complex forms and components addition and more tunnels to this set can provide the crafts with better performance.

To obtain the optimum hull form is one of the most important problems in the design of these crafts which is possible by changing the form of the body and the hydrodynamic analysis iteratively. Therefore, it is essential to achieve a quick way to generate this form and applying the body changes automatically. The basic geometrical hydrodynamic parameters of this type of hull form and the creative generation method, the following sections are described the method and some models are generated.

### 2.2 Model description

In this work, to design the tunnel crafts form, hull form is divided into two main parts that it is predicted to have the highest effect on the hydrodynamics behavior independently. These two parts are as follows:

a) Prismatic Body: In this part, the main parameters are: (1) the width of the prismatic body, (2) the deadrise angle at each longitudinal section, and (3) the longitudinal profile variations of these two parameters.

b) Tunnel: The most important parameters in this section are the width and height of tunnel and the longitudinal variations profile of these two parameters. Besides these factors, the tunnel cross section is also an effective parameter.

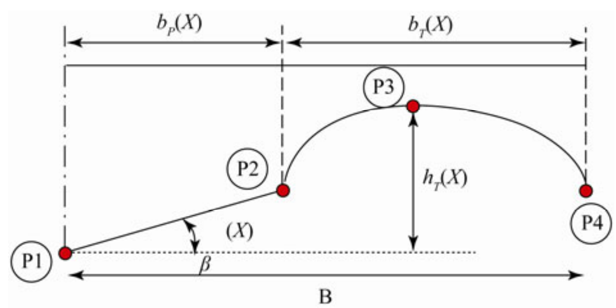


**Fig. 3 Different parameters of tunnel craft section (half-breadth section) at the length of *x***

These parameters are illustrated in Fig. 3 (half-breadth section) and also introduced in rows 1 to 4 of Table 1. Usually in this craft type, the body breadth from fore to aft changes a little, so it is assumed to be constant. Therefore, the summation of the prismatic width and tunnel parts is always constant and equals to the total width of the craft. The height of the tunnel can change based on length and it changes with the width variations of the tunnel in length can change the longitudinal cross section of the tunnel. Also this variation of width and height of tunnel can cause the twist, shrinking or enlargement the tunnel cross section. Decreasing or increasing the deadrise angle can change the shape of the prismatic part and in fact change the hydrodynamic lift force.

Based on this discretization, the tunnel craft generally is concerned as a combination of the two parts: tunnel and prismatic part. In this composition, each of the parameters introduced above, are calculated in the optimum state and ultimately the tunnel craft is designed. Therefore, the deadrise angle, prismatic body width, tunnel cross section (circle, ellipse, parabola, *etc*.), the tunnel width and height in each longitudinal section must be determined. The best way for fairing the created volume by joining longitudinal sections, is continuous variation of these parameters based on craft length. Thus, longitudinal function of each parameter should be determined until the curve of variation of these parameters is created continuously and the produced volume is generated quite smooth. The separation of these two parts of a tunnel craft is displayed in Fig. 5.

**Table 1 Definition of the parameters**

| Row | Symbol | Value /m | Description |
|---|---|---|---|
| 1 | $b_T(x)$ | | Tunnel width |
| 2 | $b_P(x)$ | | Prismatic part width |
| 3 | $h_T(x)$ | | Tunnel height |
| 4 | $\beta(x)$ | | Deadrise angle |
| 5 | $B$ | 4 | Craft width |
| 6 | $L$ | 15 | Craft length |
| 7 | $H$ | 2 | Craft height |
| 8 | $B_v$ | 1.5 | Maximum Prismatic part width |
| 9 | $D_{11}$ | 1.5 | Height of the fore point of line 1 |
| 10 | $D_{20}$ | 0.25 | Height of the aft point of line 2 |
| 11 | $D_{31}$ | 1.75 | Height of the fore point of line 3 |
| 12 | $D_{30}$ | 1 | Height of the aft point of line 3 |
| 13 | $D_{41}$ | 1.25 | Height of the fore point of line 4 |
| 14 | $D_{40}$ | 0.25 | Height of the aft point of line 4 |
| 15 | $n$ | 15 | Number of longitudinal sections |
| 16 | $m_1$ | 5 | Number of points between lines 1 and 2 in each longitudinal section |
| 17 | $m_2$ | 15 | Number of points between lines 2 and 3 in each section |
| 18 | $m_3$ | 15 | Number of points between lines 3 and 4 in each section |
| 19 | $C_{11}$ | 30 | Percentage of length of fixed part of line 1 from aft craft |
| 20 | $C_{21}$ | 30 | Percentage of length of the fixed part of line 2 from aft craft |
| 21 | $C_{31}$ | 30 | Percentage of length of the fixed part of line 3 from aft craft |
| 22 | $C_{41}$ | 30 | Percentage of length of the fixed part of line 4 from aft craft |
| 23 | $C_{b32}$ | 50 | Percentage of closing of the line 3 to line 2 |
| 24 | $Z_i(x)$ , $Y_i(x)$ | | Width and height functions of guideline $i$ |

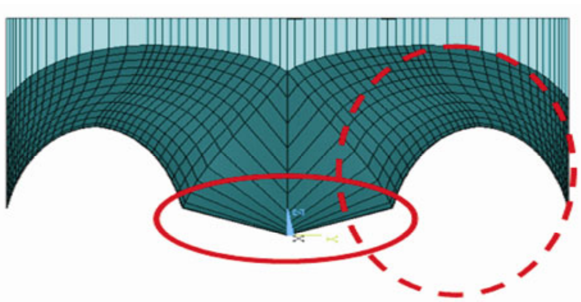

**Fig. 4 Body plan of tunnel craft. (Prismatic part and tunnel are demonstrated by solid line and dash line, respectively)**

Based on this discretization in the hull form of the tunnel craft, four different lines can be distinguished. These lines can be seen in Figs. 5 and 6. The line 1 is the symmetric line of the craft body and prismatic part. Line 2 is the boundary between the prismatic part and tunnel. Line 3 and 4 are the maximum height location of the tunnel and the side boundary of the tunnel and craft, respectively. These four lines in each longitudinal section specify four points that by use of them the section can be established. These four points in a section with the length of $x$ are shown in Fig. 4. As can be seen in this figure, the prismatic part is made of straight connection between points 1 and 2. The tunnel is produced by connecting points 2, 3 and 4. By changing the height and width ratios of the point 2 to point 1, the deadrise angle and width of the prismatic part are changed, respectively. Also, if the total craft width is constant, division of width between prismatic part and tunnel is achieved by changing the width of the point 2. The relative displacement of points 2, 3 and 4 changes the tunnel cross section, its width and height. The point 3 of tunnel can be inclined to the left or right that can be important for the generation of circulating flow. These changes can be applied to each longitudinal cross section. By relative displacement of points of two adjacent sections, the variation curve of each of the parameters mentioned above can be controlled.

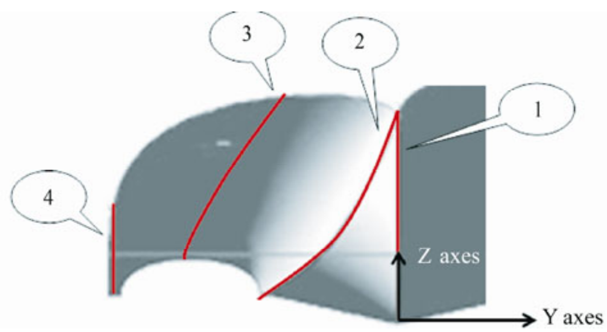


**Fig. 5 Front view of the generated body by use of guide lines**

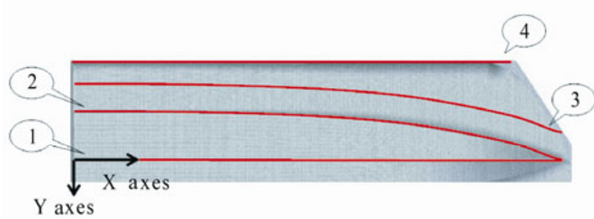


**Fig. 6 Bottom view of the generated body by use of guide lines**

### 2.3 Definition of the model parameters

The proposed method in this paper for generation of the tunnel craft model is based on the use of four lines, introduced in the previous section, that are named the guidelines henceforth. By defining functions for these four guidelines based on length position ($x$), the four points and cross section are created then by connecting these sections; the 3D model of craft is produced.

As can be seen in Figs. 6 and 7 the guidelines characteristics can be summarized as:

- Line 1 is the symmetry line of prismatic part and craft. The height of this line is varying along the craft length only and its transverse position is fixed ($z_1=z(x)$, $y_1=0$).
- Line 2 is the side line of the prismatic part and tunnel and it is connecting these two parts. The height and transverse position of this line is changing along the craft length ($z_2=z(x)$, $y_2=y(x)$).
- Line 3 is the middle line of the tunnel. The height and transverse position of this line is also changing along the craft length and the maximum height of the tunnel is associated with this line ($z_3=z(x)$, $y_3=y(x)$).
- Line 4 is the side line of the craft and the tunnel. The height of this line is changed along the craft length only and its transverse position is fixed ($z_4=z(x)$, $y_4=B/2$).

With controlling these four lines, all the parameters mentioned in the previous section can be adjusted.

- Craft width = twice the transverse distance between lines 1 and 4
- Tunnel width = transverse distance between lines 2 and 4 in each longitudinal section
- Prismatic part width = transverse distance between lines 1 and 2 in each longitudinal section
- Deadrise angle = the ratio of height difference of points of lines 1 and 2 to their width difference in each longitudinal section
- Tunnel height = the height difference between line 1 and 3 in each longitudinal section
- The tunnel sections form= connecting the three points of lines 2, 3 and 4 by a curve (Spline, circle, ellipse or parabola) in each longitudinal section. This section form of the tunnel is affected by tunnel width and height.

Thus, using the defined four guidelines, all parameters of hull form can be determined. The parameters of hull form are changed via the guidelines data.

To define these guidelines the control parameters are used as input values to adjust and control the guidelines. The overall length, width and height of the craft (rows 5 to 7 in Table 1) are determined as the first input values by the user. The maximum prismatic body width (row 8), which happens at the end of the craft, is assumed as the next input data. The height of the beginning and end points of the guidelines (rows 9 to 14 in Table 1) are defined in terms of longitudinal position ($x$) to obtain the constant coefficients of equations of the guidelines. Lines 1 and 2 have the same point at the beginning. The width of line 3 which is between lines 2 and 4 is defined based on its adjacency distance to line 2 (row 23 at Table 1). It should be noted that according to the type of the body form, all changes along these guidelines occur on 1/3 or 1/2 of the beginning craft length and at the end of the craft, the rates of variations are very small or almost constant. Therefore, the parallel lengths of these guidelines (not changed) are defined based on the percentage of the length craft (rows 19 to 22 at Table 1).

**2.4 The governing relations**

According to the presented model in the previous section, the governing mathematical relations are described in this section. In this paper, two different methods are used to define the four guidelines. In the first method, quadratic and cubic functions are employed to define guidelines. In the second method, Spline function is used to define guidelines. To define each longitudinal section with four points of guidelines, three different methods have been used. In all three methods, prismatic body is produced by direct connection (straight line) of point 1 to point 2 in each section (for instance see Fig. 4). Three different methods, (parabolic, elliptic and Spline curve) used to define the tunnel between points 2, 3 and 4. The summary of how to define these three different models are described in Table 2.

**Table 2 The conditions employed in three different models**

| Model | Definition type of guideline | Definition type of prismatic body | Definition type of tunnel |
|---|---|---|---|
| First | Second order polynomial | Straight line | Parabolic |
| Second | Second order polynomial | Straight line | Elliptic |
| Third | Third order Spline | Straight line | Third order Spline |

Afterward, with relations of the quadratic curve, four guidelines have been defined as are presented in the following that are used for the production of models 1 and 2. The width and height functions in each of these guidelines are defined by the length position ($x$). To determine the constant coefficients of the quadratic relations of each guideline, three boundary conditions are needed that are proposed for the definition of each guideline. These conditions are obtained based on the beginning and end points of each guideline which are entered by the user as input data. In Table 1, rows 9 to 14, indexes and values of these parameters has been given. Because the most of these hull forms have a uniform cross section in the aft of craft, the variations of guidelines should also be constant in some percentage of the length craft from aft. For this purpose, a number of coefficients are assumed in the equations that their definitions, indexes and values are observed in rows 19 to 22 in Table 1. These coefficients are used in the definition of boundary conditions of the guidelines. For simplicity and to reduce the input parameters, the transverse position of the guideline 3 is defined based on the closing percentage coefficient of to the guideline 2. The definition, index and value of this coefficient are expressed in row 23 in Table 1. The governing mathematical definitions are described as follows for four lines.

A) Line 1 definition:

To obtain the constant coefficients of this guideline, its height variations in some percentages of the aft length are assumed equal to zero and according to that the end of this line has the lowest height, the end height of the guideline 1 is set to zero and in front of the craft is assumed based on the input height of the beginning point of guideline 1 ($D_{11}$). This guideline is the symmetry line of the craft and its width from beginning to end is zero. The result is expressed as follows

*B.C.* :

$$Z_1(X=L*C_{11})=0,\ \frac{\mathrm{d}Z_1}{\mathrm{d}x}(X=L*C_{11})=0,\ Z_1(X=L)=D_{11}$$

$$\Rightarrow Z_1(X)=\frac{D_{11}}{L^2*(C_{11}{}^2-2*C_{11}+1)}*X^2+ \frac{-2*C_{11}*D_{11}}{L*(C_{11}{}^2-2*C_{11}+1)}*X+\frac{C_{11}{}^2*D_{11}}{(C_{11}{}^2-2*C_{11}+1)}$$

$$\Rightarrow Y_1(X)=0 \tag{1}$$

B) Line 2 definition:

To obtain the constant coefficients of this guideline, the variations of its height and width at the aft length percentage, are assumed equal to zero and the end height of the guideline 2 is set based on the input data ($D_{20}$) for the line end point parameter. According to connecting of the guidelines 1 and 2 at the front of the craft, the fore height of this guideline is assumed based on the input data for the beginning point of guideline 1 ($D_{11}$). The guideline width at aft craft length is set equal to the maximum prismatic width ($B_v$).

*B.C.*:

$$Z_2(X=L*C_{21})=D_{20},\ \frac{\mathrm{d}Z_2}{\mathrm{d}x}(X=L*C_{21})=0,\ Z_2(X=L)=D_{11}$$

$$\Rightarrow Z_2(X)=\frac{D_{11}-D_{20}}{L^2*(C_{21}{}^2-2*C_{21}+1)}*X^2+ \frac{2*C_{21}*(D_{20}-D_{11})}{L*(C_{21}{}^2-2*C_{21}+1)}*X+ D_{11}+\frac{(1-2*C_{21})*(D_{20}-D_{11})}{(C_{21}{}^2-2*C_{21}+1)}$$

*B.C.*:

$$Y_2(X=L*C_{21})=B_v,\ \frac{\mathrm{d}Y_2}{\mathrm{d}x}(X=L*C_{21})=0,\ Y_2(X=L)=0$$

$$\Rightarrow Y_2(X)=\frac{-B_v}{L^2*(C_{21}{}^2-2*C_{21}+1)}*X^2+ \frac{2*C_{21}*B_v}{L*(C_{21}{}^2-2*C_{21}+1)}*X+\frac{(1-2*C_{21})*B_v}{(C_{21}{}^2-2*C_{21}+1)} \tag{2}$$

C) Line 3 definition:

The order of this polynomial equals to 3 and it has four constant coefficients. To obtain these constant values, the height variations in the aft percentage of length, are set zero and the height of the end and fore of the guideline are assumed based on the input data ($D_{30}$, $D_{31}$). The guideline width is defined based on the ratio of its closing to line 2 ($C_{b32}$) between lines 2 and 4.

*B.C.*: $Z_3(X=L*C_{31})=D_{30}$,

$$\frac{\mathrm{d}Z_3}{\mathrm{d}x}(X=L*C_{31})=0,\ Z_3(X=L)=D_{31},\ \frac{\mathrm{d}Z_3}{\mathrm{d}x}(X=L)=0$$

$$\Rightarrow Z_3(X)=\frac{-2*(D_{31}-D_{30})}{L^3*(C_{31}{}^2-2*C_{31}+1)*(1-C_{31})}*X^3+ \frac{3*(D_{31}-D_{30})*(1+C_{31})}{L^2*(C_{31}{}^2-2*C_{31}+1)*(1-C_{31})}*X^2+ \frac{-6*(D_{31}-D_{30})*C_{31}}{L*(C_{31}{}^2-2*C_{31}+1)*(1-C_{31})}*X+ D_{31}+\frac{(D_{31}-D_{30})*(-1+3*C_{31})}{(C_{31}{}^2-2*C_{31}+1)*(1-C_{31})}$$

$$\Rightarrow Y_3(X)=C_{b32}*Y_2(X)+(1-C_{b32})*B/2 \tag{3}$$

D) Line 4 definition:

To obtain the constant coefficients of this guideline, the guideline 4 height variations in the aft percentage of the length, are set as zero and the end and fore heights of the guideline 4 are assumed based on the input data ($D_{40}$, $D_{41}$) for the beginning and end points of the line. This guideline is the side line of the craft and its width from beginning to end equals to half of the craft width.

*B.C.*:

$$Z_4(X=L*C_{41})=D_{40},\ \frac{\mathrm{d}Z_4}{\mathrm{d}x}(X=L*C_{41})=0,\ Z_4(X=L)=D_{41}$$

$$\Rightarrow Z_4(X)=\frac{D_{41}-D_{40}}{L^2*\left(C_{41}^2-2*C_{41}+1\right)}*X^2+ \frac{-2*C_{41}*(D_{41}-D_{40})}{L*\left(C_{41}^2-2*C_{41}+1\right)}*X+D_{41}+\frac{(2*C_{41}-1)*(D_{41}-D_{40})}{\left(C_{41}^2-2*C_{41}+1\right)}$$

$$\Rightarrow Y_4(X)=B/2 \tag{4}$$

With the identified quadruplet points in each longitudinal section, the curve of tunnel can be determined by the definition type of the tunnel shape. For the tunnel with a parabolic curve, if the width values are given between points 2 and 4, the height of the points on the parabolic curve can be obtained by following matrix equations.

$$\begin{Bmatrix} Z_2\\ Z_3\\ Z_4 \end{Bmatrix}=\begin{bmatrix} Y_2^2 & Y_2 & 1\\ Y_3^2 & Y_3 & 1\\ Y_4^2 & Y_4 & 1 \end{bmatrix}*\begin{bmatrix} a\\ b\\ c \end{bmatrix} \Rightarrow \begin{bmatrix} a\\ b\\ c \end{bmatrix}=\begin{bmatrix} Y_2^2 & Y_2 & 1\\ Y_3^2 & Y_3 & 1\\ Y_4^2 & Y_4 & 1 \end{bmatrix}^{(-1)}*\begin{Bmatrix} Z_2\\ Z_3\\ Z_4 \end{Bmatrix}$$

$$\Rightarrow\ Z_i=\begin{bmatrix} Y_i^2 & Y_i & 1 \end{bmatrix}*\begin{bmatrix} a\\ b\\ c \end{bmatrix} \quad Y_2\le Y_i\le Y_4 \tag{5}$$

Also, if the oval shape is desired for the tunnel cross section, the following relations between points 2, 3 and 4 can be used. By assuming arbitrary width between the width values of points 2 and 4, the height of points on the ellipsoid is obtained. It should be noticed in this type of cross section, because of its shape, there is a limitation that the transverse position of the third guideline should always be in the middle of the width of guidelines 2 and 4.

$$a=\sqrt{(\frac{Y_4-Y_2}{2})^2+(\frac{Z_4-Z_2}{2})^2} \quad b=\sqrt{(Y_3-\frac{Y_4+Y_2}{2})^2+(Z_3-\frac{Z_4+Z_2}{2})^2}$$
$$\Rightarrow Z_i=b*\sqrt{1-\frac{Y_i-\frac{Y_4+Y_2}{2}}{a}}+\frac{Z_4+Z_2}{2} \qquad Y_2\le Y_i\le Y_4 \tag{6}$$

To create guidelines and tunnel sections in the model 3, the third order Splines is used. The relations used for this context are expressed as:

$$C(u)=\frac{\sum_{i=0}^{n}N_{i,p}(u).w_i.P_i}{\sum_{i=0}^{n}N_{i,p}(u).w_i},\ U=\{u_0,u_1,....,u_{r-1},u_r\},\ 0\le u_i<u_{i+1}\le 1 \tag{7}$$

where:

$$N_{i,p}=\begin{cases}\text{if } p>0\Rightarrow\ N_{i,p}=\frac{u-u_i}{u_{i+p}-u_i}N_{i,p-1}+\frac{u_{i+p+1}-u}{u_{i+p+1}-u_{i+1}}N_{i+1,p-1}\\ \text{if } p=0\Rightarrow\ N_{i,0}=\begin{cases}1 & u_i\le u<u_{i+1}\\ 0 & \text{otherwise}\end{cases}\end{cases} \tag{8}$$

In these relations, $p$, the order of curve equals to 3, $n$, the number of control points equals to 6, $r$, the size of knot vectors equals to 10 and $P_i$, the coordinate vector of control points, $w_i$, the weight of each of these control points, and $U$, is the knot vector. According to the presented relationships, for each guideline or section curves of the tunnel, the knot vectors, control points and their weights are assumed as optional values. With the proper control of these parameters, the shape of the curve can be changed and adjusted.

## 3. Results and discussion

### 3.1 Comparison of the proposed models

The three created models for constant and the same input data are plotted and compared together. First sections of these are shown in Figs. 7, 8 and 9 for the first, second and third models, respectively. In these figures, the front view of body plan lines is shown. In all three models the input geometry parameters are assumed to be equal. According to Table 1, the craft length, craft width and maximum prismatic body width are assumed as 15, 4 and 1.5 meters, respectively. The other parameters and their values are given in Table 1.

Based on these values and equations of (1-4), the functions of guidelines for first and second models are obtained. For the first model, the offset equations ($Y_i$,$Z_i$) are given in terms of $X$ as follows:

$$\begin{cases}Z_1=0.0136X^2-0.1224X+0.2755\\ Y_1=0\\ Z_2=0.0113X^2-0.1020X+2.5204\\ Y_2=0.0136X^2+0.1224X+1.2244\\ Z_3=-0.0013X^3+0.0379X^2-0.2624X+1.5313\\ Y_3=0.5X^2+1\\ Z_4=0.0091X^2-0.0816X+0.4337\\ Y_4=2\end{cases} \tag{9}$$

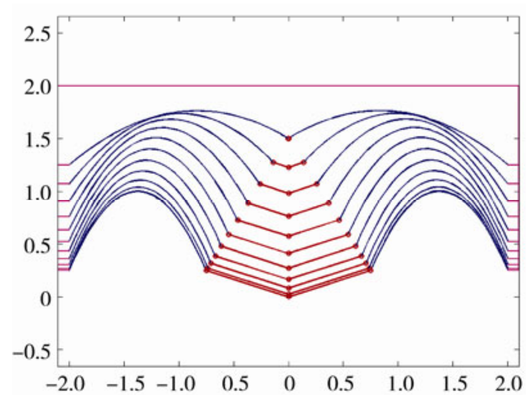


**Fig. 7 The first model based on quadratic curves**

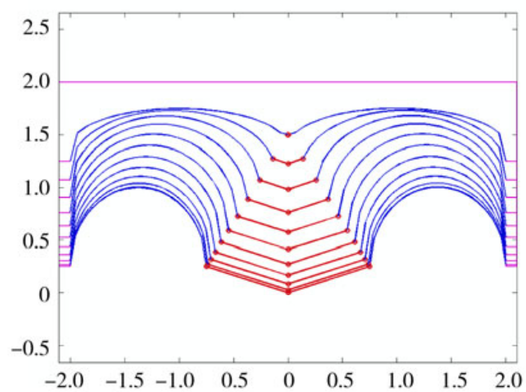


**Fig. 8 The second model based on Spline and quadratic curves**

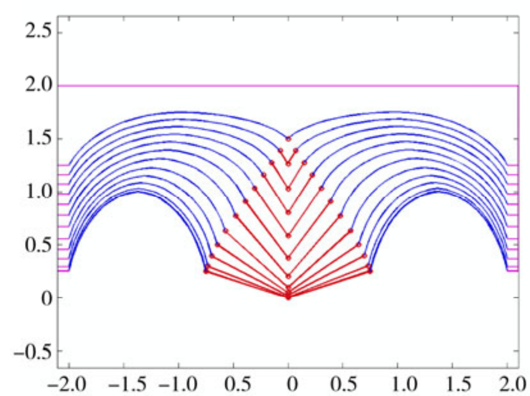


**Fig. 9 The third model based on Spline curves**

As an example, the produced surface of the third model is shown in Fig. 10. By the use of generated points, firstly, the curves and then the surfaces are made.

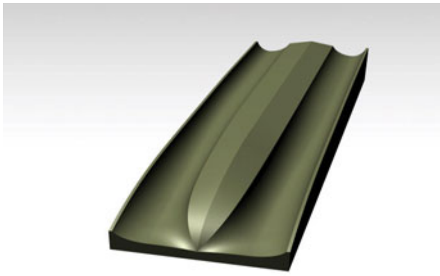

**Fig. 10 The bottom view of generated surface from third model**

In the case of the second model, means elliptic, there is a limitation that it is not possible for guideline 3 to locate in the other positions except of at the middle of guidelines 2, 4 distance. So, the value of parameter $C_{b32}$ is 50%.

**3.2 Effect of the main geometry parameters variations**

The changes in the geometry of the model are studied by changing the first model (quadratic one) parameters. In Fig. 11, the result of this change in two models parameters can be seen.

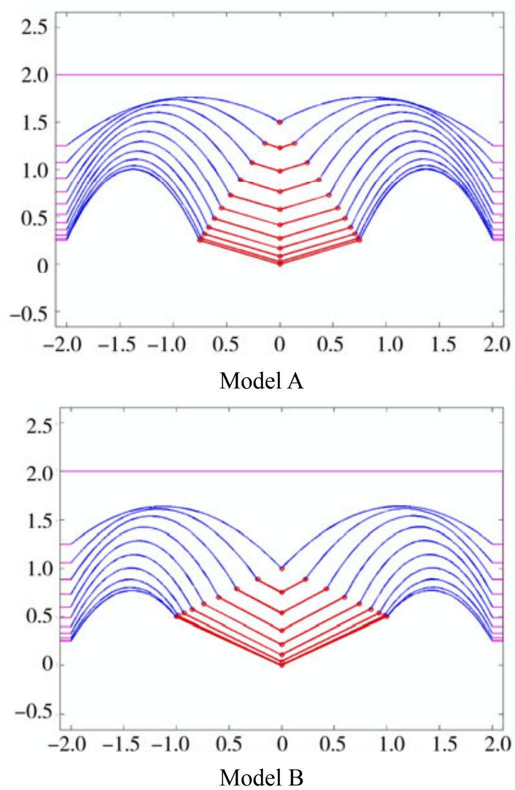


**Fig. 11 The result of changes in geometry parameters**

The difference between two models parameters are summarized in Table 3. The prismatic body width (row 4) and the parallel parts of four guidelines (rows 11 to 14) are greater in model B in comparison with model A. At height of the beginning and the end points of guidelines (rows 5 to 10) also some changes has been applied. The height of the front points of guidelines 1, 3 and end points of guideline 3 have been reduced from model A to model B. The height of end point of the guideline 2 is greater in model A than model B. The beginning and end points of the guideline 4 are remained constant. The guideline 3 has been closer to line 2 (row 15). As it can be seen, with these changes, the deadrise angle is increased and the tunnel section shape has been changed and the height and width of it are decreased.

**3.3 Effect of the sub-parameters variations**

In the first and second models, all geometry parameters that control the form of the body are presented in Table 3. But in the case of the third model, because of using Splines to define guidelines and tunnel sections curvature, using the parameters of knot vectors and control points may create every shape of the hull form.

In the other words, this model has a better ability for control and adjustment than the other two models. Although, when the number of parameters is increased, their fitting and consonance are became difficult and take more time. By use of the third model, with the same basic parameters according to Table 1, two models have been generated, as presented in Table 4.

**Table 3 The values of geometry parameters of two models and their variations**

| Row | Parameter | Model A /m | Model B /m |
|---|---|---|---|
| 1 | $B$ | 4 | 4 |
| 2 | $L$ | 15 | 15 |
| 3 | $H$ | 2 | 2 |
| 4 | $B_v$ | 1.5 | 2 |
| 5 | $D_{11}$ | 1.5 | 1 |
| 6 | $D_{20}$ | 0.25 | 0.5 |
| 7 | $D_{31}$ | 1.75 | 1.5 |
| 8 | $D_{30}$ | 1 | 0.75 |
| 9 | $D_{41}$ | 1.25 | 1.25 |
| 10 | $D_{40}$ | 0.25 | 0.25 |
| 11 | $C_{11}$ | 30 | 50 |
| 12 | $C_{21}$ | 30 | 45 |
| 13 | $C_{31}$ | 30 | 40 |
| 14 | $C_{41}$ | 30 | 35 |
| 15 | $C_{b32}$ | 50 | 70 |

**Table 4 The values of coordinates of control points (CP) in two models**

| Guideline 1 | CP 1 | CP 2 | CP 3 | CP 4* | CP 5* | CP 6 |
|---|---|---|---|---|---|---|
| X | 0 | 4.275 | 4.5 | 8 / 13.25 | 9.75 / 15 | 15 |
| Y | 0 | 0 | 0 | 0 | 0 | 0 |
| Z | 0 | 0 | 0 | 0.05 / 0.975 | 0.25 / 1.15 | 1.5 |
| W | 1 | 1 | 1 | 1 | 1 | 1 |
| **Guideline 2** | | | | | | |
| X | 0 | 4.275 | 4.5 | 8 / 11.5 | 9.75 / 13.25 | 15 |
| Y | 0.75 | 0.75 | 0.75 | 0.625 / 0.575 | 0.375 / 0.4875 | 0 |
| Z | 0.25 | 0.25 | 0.25 | 0.583 / 0.916 | 0.916 / 1.0625 | 1.5 |
| W | 1 | 1 | 1 | 1 | 1 | 1 |
| **Guideline 3** | | | | | | |
| X | 0 | 4.275 | 4.5 | 8 | 9.75 | 15 |
| Y | 1.375 | 1.375 | 1.375 | 1.3125 / 1.2875 | 1.0625 / 1.2 | 1 |
| Z | 1 | 1 | 1 | 1.2 / 1.5 | 1.4 / 1.625 | 1.75 |
| W | 1 | 1 | 1 | 1 | 1 | 1 |
| **Guideline 4** | | | | | | |
| X | 0 | 4.275 | 4.5 | 8 | 9.75 | 15 |
| Y | 2 | 2 | 2 | 2 | 2 | 2 |
| Z | 0.25 | 0.25 | 0.25 | 0.516 / 0.416 | 0.783 / 0.583 | 1.25 |
| W | 1 | 1 | 1 | 1 | 1 | 1 |

* value of first model / value of second model
All values are in given in meter.

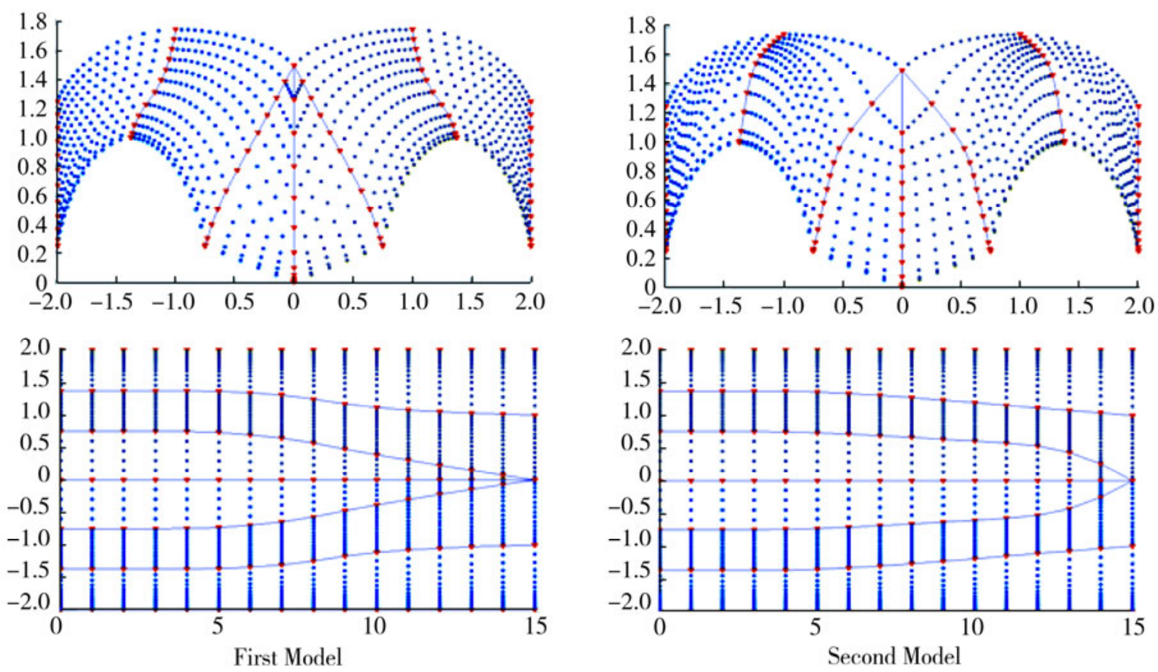


**Fig. 12 The effect of control points change in two Spline models**

As it may be noticed, 6 control points are used to define third order Spline curve. The control points 4 and 5 only have been changed in all 4 lines. The displacement of the control points changes the guidelines form and as a result of that, the body form is changed. As it can be seen in the Fig. 12, the volume of the prismatic body in second model is became larger than first model and it has a large width from front of the craft. But on the other side, in the first model, this part is thinner and smaller in volume. These changes also have affected the shape of the tunnel and especially in front of craft, the curvature of the second tunnel model has been larger than the first.

In the Spline model, the number of control points and the size of knot vectors have the increasing capability. By this work, the position adjustment of the control points to control and achieve the desired hull form can be done more accurately. But by this way, the additional input data and assumptions, increase the complexity and time consumption to generate the geometric model that this cost should be paid to achieve greater accuracy.

## 4 Conclusions

By using the proposed method and the prepared code in this research, the geometric model of tunnel planning craft with the minimum number of related input parameters, that are 15, can be generated. Obviously, the generated model is used to primary study and for optimization in conceptual design step. After the finalization of the main hull form, more details can be added such as longitudinal or transverse steps for improvement of craft hydrodynamics behavior. The rapid generation of hull form by present method is very important. In addition, the produced model is much precise and it is completely smooth that can be transferred to the mesh generation software to generate computational model and can be used for computational fluid dynamics analysis.

In comparing the three generation methods of hull form, it can be stated that the second model (elliptic) has the most limitations between these models and because of this is the least flexible one. The first model (parabolic) has the middle limitations and there is a relative balance between the limitations and its ability to control the geometry. Finally, in the third model (Spline) due to sub-parameters (knot vectors, control points …); the definition of the model would be more time consuming and complex. From the other hand, the produced model has the more control ability and flexibility than the other two models. Also, because of the using Spline curves, the distance between production points are adjustable at each section and density of them can be controlled.

This method for generation of the planning tunnel craft hull form with minimum parameters, least time and proper accuracy is an optimal method and the main limitation of that is the fixed craft width across the whole length from the beginning to end.

Finally, it should be noted that the generated hull form by the presented developed code here using input geometry parameters such as length, width, etc., should be examined to investigate its hydrodynamic performance and study about the effective parameters. Our preliminary studies show that the third hull form model (i.e. generated by Spline method) has a good hydrodynamic behavior. Currently, we are dealing with these research issues and the complementary CFD results concerning the hydrodynamic performance of the designed planning tunnel high speed craft, so it will be presented in a next paper.

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**Morteza Ghassabzadeh** is a PhD candidate of marine hydrodynamics at Department of Ocean Engineering, Amirkabir University of Technology (AUT). His current research interests include ship hull modeling, hydro-elasticity and CFD.

**Hassan Ghassemi** is an associate professor at department of Ocean Engineering, Amirkabir University of Technology (AUT). His current research interests include marine propulsor design, high-speed crafts, and hydrodynamic numerical methods such as BEM and CFD.