Front Surface Geometry Modeling of Remotely Operated Vehicle (ROV) Body Observation Class

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Abstract. Sunda Strait of Indonesia needs a technology to find out information on the bottom of Sunda Strait, and the suitable technology is ROV. The existing ROVs have limitations; those are in design structure and hydrodynamic response. An early research on design concepts has been conducted to develop existing ROVs. This research has a purpose to develop existing ROVs and to continue preliminary research on design concepts of the ROVs, and also to obtain the best front surface geometry modeling of the ROV body. The method used was the Granville method which determines parametric profile on ROV body which had streamlined body geometry. The result of the research was to obtain K_1(curvature at x_m) and r_n (radius of the curvature at front end part) modeling, so that the best front surface geometry modeling curve on the body of the ROV Observation Class can be found.

INTRODUCTION

Remotely Operated Vehicle (ROV) is underwater observation equipment used to collect information in a form of visual image or data obtained from sensor. Sunda Strait is a strategic strait in Indonesia which connects Java and Sumatra Island. To support Sunda Strait, Remotely Operated Vehicle (ROV) was developed to gain access to information around Sunda Strait, especially on its lower surface, where ROV uses a propeller as an observator[1,2]. Sea floor of Sunda strait is working environment of liquid for moving object on it, in which it gives hydrodynamic effect toward outer surface and hydrodynamic moment. The effect requires the moving object in liquid which has hydrodynamic friendly design. The existing ROV used in Sunda Strait had less optimal results, especially in the design structure of the hydrodynamic response[3]. The hydrodynamic response is affected by the geometry that moves in the fluid[4]. Preliminary research had been carried out to overcome this problem, by doing optimization the design by developing the initial concept of the ROV body using the method of concept screening and concept. The result of the preliminary research was to gain the best concept, where the best concept was a small ROV with a streamlined / half-streamlined body geometry[5]. This research is a development of the existing ROV and also a continuation of the previous research, which aims to obtain the best front surface ROV geometry modeling[4].

METHOD

Important consideration in designing sub marine vehicle is the equipment of fore body geometry. A good design, considered from fineness ratio L/D, has linear correlation of drag coefficient. In addition for body geometry has contribution toward drag value and prevents cavitations. Fore body geometry is required because it gives good pressure distribution and low drag. From the literature, methodology used to regulate geometry curvature. This study used parametric method[5,6] in literature consideration[7]. Parametric profile of ROV body which has streamlined

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geometry body was determined using Granville method[5,8]. In determining parameter definition of ROV body, general equation of Granville method was used.

$$Y(X) = Y(\sum_{i=1}^{N} a_i F_i(X), G(X)) \qquad (1)$$

Analysis of parametric profiles and body design of the ROV was conducting by suing fixed variables that have been used by Wiryadinata (2017)[3]. Assuming that the number, dimensions and requirements of the components used are the same and the configuration of the components in the vehicle is ignored. The parametric profile of the ROV body that has the streamlined body geometry is determined by the Granville method (2006)[6]. The streamlined hydrodynamic was classified in two classes; Five-parameter Rounded nose, Pointed-Tail Body; and Eight-Parameter Rounded-Nose, Tailboom Body. In this research the design of the ROV body uses five parameters to simplify in manufacturing and analysis. The example of a body with five parameters is shown as in Figure 1. Forebody or the front part ($0 \leq X \leq Xm$) is defined with -4 degree polynomials, meanwhile the rear part ($Xm \leq X \leq L$) defined with -5[5] degree polynomials.

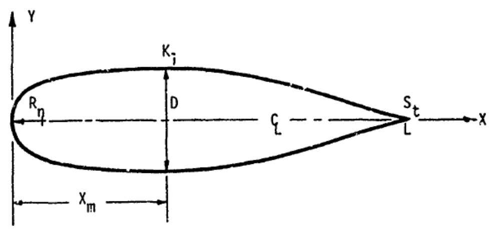

FIGURE 1. Rounded-Nose pointed tail body[5]

Six dimensional parameter defined in figure are: r_n (curvature radius at the front end), D (maximum diameter), x_m (axial location of maximum diameter), k_1 (curvature at x_m), L (total of length). These six parameters can be reduced to five parameters which are non-dimensional parameters (non-dimensional), so that it is called as five-parameter: r_n (non-dimensional curvature radius at the front end), f_r (fineness ratio), x_m (non-dimensional axial location from the maximum diameter), and k_1 (non-dimensional curvature at x_m).

$$\frac{Y(X)}{L} = \frac{1}{2f_r}\left[r_n F_1(x) + k_1 F_2(x) + G(x)\right]^{1/2} \qquad (2)$$

whence:

$$x = \frac{X}{X_m}$$

$$F_1(x) = 2x(x-1)^3$$

$$F_2(x) = -x_2(x-1)^2$$

$$G(x) = x^2(3x^3 - 8x + 6)$$

Equation of x, $F_1(x)$, $F_2(x)$, and G(x) were formed from equation (1) by expressed quadratic polynomial equation from non dimensional boundary condition. Equation x, $F_1(x)$, $F_2(x)$, and G(x) were substituted general equation of parametric geometric (1), and by knowing the fineness ratio the general equation of parametric geometric for determined size was obtained.

RESULT

The limits used in solving the vehicle geometry differential equations are as follows. $Y(0) = 0$, $Y'(0) = \infty$ or $dX/dY]_{x=0} = 0$, $1/d^2X/d^2Y]_{x=0} = 0$, $Y(x_m) = D/2$, $Y'(x_m) = 0$, $Y''(x_m) = k_1$. Completion of equations refers to the assumption of vehicle geometry, there is no infected forebody (Noninflected), there is no change in the shape of the curve, there is an undesired inflection, so the value of r_n and k_1 has a solution to the inflection limit. Analytic equation for five parameters of geometry formed from the multiplication of -4 degree polynomial equation for fore body of vehicle and the combination of fineness ratio of body dimension. The -4 degree polynomial equation was accomplished by substituting equation. Thus, the -4 degree polynomial equation for the front part of the vehicle is defined as follows;

$$y^2 = r_n F_1(x) + k_1 F_2(x) + G(x) \tag{3}$$

$$y^2 = r_n[-2x(x-1)^3 + k_1(-x^2(x-1)^2) + x^2(3x^3 - 8x + 6)] \tag{4}$$

By substituting the prerequisite of analysis of L= 500 mm and D=180 mm which fulfilled the value of fineness ratio it was obtained geometry parametric equation of ROV body. The basic parametric equation was use to form streamlined geometry suitable for length to diameter ratio of major streamlined body.

$$\frac{Y(X)}{L} = \frac{1}{2f_r}\{r_n[-2x(x-1)^3 + k_1(-x^2(x-1)^2) + x^2(3x^3 - 8x + 6)]\}^{1/2} \tag{5}$$

$$Y(X) = 3.5\{r_n[-2x(x-1)^3 + k_1(-x^2(x-1)^2) + x^2(3x^3 - 8x + 6)]\}^{1/2} \tag{6}$$

The boundary condition used in geometric differential equation of vehicle body were Y(0), $Y_1(0)$, Y'(X), Y''(X). Those boundary conditions were used to obtain R_n and K_1 values which was streamlined geometric curvature equation. The differentiation equation (6) which was the basic *streamlined* equation, with boundary condition (*X*) was needed for certain condition. This condition was critical point and maximum point $(X)^6$. Critical point and maximum point are the point where the value of x in boundary solution of inflection equal to 0 and 2 respectively. Critical point of vehicle body geometry was used to obtain r_n with the boundary condition of 1 to 3 based on boundary of curve inflection, those are: x, k_1, and r_n.

By inputting-4 degree polynomial equation into the equation (2) it was obtained equation as follows;

$$\mathrm{Y(X)} = 3.5\{\mathrm{r_n}[-2\mathrm{x}(\mathrm{x}-1)^3 + \mathrm{k_1}(-\mathrm{x}^2(\mathrm{x}-1)^2) + \mathrm{x}^2(3\mathrm{x}^3 - 8\mathrm{x} + 6)]\}^{1/2} \tag{7}$$

The critical point of vehicle geometry was used to obtain the r_n curve with conditions boundaries 1 to 3 based on the inflection boundary curve solution as follows: $x = 0$, $r_n = 0$, $k_1 = 4$, so that the equation (7) becomes:

$$\mathrm{Y(X)} = 3.5(-\mathrm{x}^4 + 2\mathrm{x}^2)^{1/2} \tag{8}$$

The verification of Y(X) fulfill the boundary condition 1, by inputting the value of x into equation (8), Y(0) = 0, $Y(0) = 3.5(-0^4 + 0^2)^{1/2}$. The value of Y(0) = 0, at critical point, axial axis-x has value of 0 (zero), Y(0), therefore it fulfill the boundary condition, so that the equation can be used further as r_n curve equation.

The equation can be used later as the r_n curve equation. Furthermore, the first and second derivatives of the equation Y (X) fulfill the predetermined boundary conditions.

$$\mathrm{r_n} = 3.5\left(-\frac{2\sqrt{-\mathrm{x}^2(\mathrm{x}^2-2)}\,(\mathrm{x}^2-1)^2}{\mathrm{x}^2(\mathrm{x}^2-3)}\right) \tag{9}$$

By describing the plot of the r_n equation into the cartesian diagram, the geometry of the front of the vehicle body was found to be effective against the dimensions of the vehicle due to the hydrodynamic effect[5]. Figure 2 is the r_n in modeling curve in the Cartesian diagram[5]. Figure 2 is a modeling curve r in a Cartesian diagram.

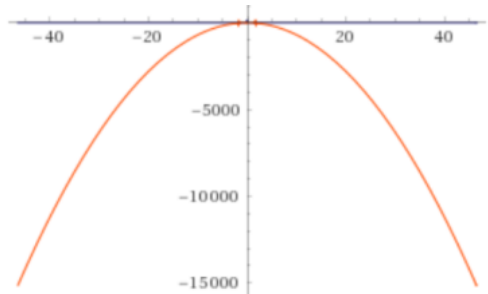

FIGURE 2. Modeling curve r_n

Curvature K_1 uses boundary conditions 4 - 6. The curvature solution K_1 uses the inflection boundary solution maximum r_n value at x_m was maximum: $x = 1$, $r_n = 2$, $k_1 = 0$. So equation (7) becomes

$$Y(X) = 3.5(-x^4 + 4x^3 - 6x^2 + 4x)^{1/2} \quad (10)$$

The verification of equation Y(X) fulfills boundary condition of 4, by inputting x value into equation (10).

$$Y(X_m)_{b.4} = \frac{D}{2} = 3.5, \textit{boundary condition of } 4$$

$$Y(X) = 3.5(-1^4 + 4x1^3 - 6x1^2 + 4x1)^{1/2}$$

$$Y(X_m) = Y(X_m)_{b.4} = 3.5 \textit{ hence } X_m \textit{ has maximum value}$$

Hence equation (10) fulfills the boundary condition of 4, This equation can be used later as the curve equation K_1. Furthermore, the first and second derivatives of the equation $Y(X)$ fulfill the predetermined boundary conditions.

$$K_1 = 3.5\left(-\frac{2(x-1)^2(x^4-4x^3+6x^2-4x-2)}{x(x^3-4x^2+6x-4))\sqrt{-x(x^3-4x^2+6x-4)}}\right) \quad (11)$$

By describing the plot of the K_1 equation into the Cartesian diagram, it is found that the geometry of the front of the vehicle body was effective against the dimensions of the vehicle due to the hydrodynamic effect[8]. Figure 3 was a modeling curve for K_1 in the cartesian diagram.

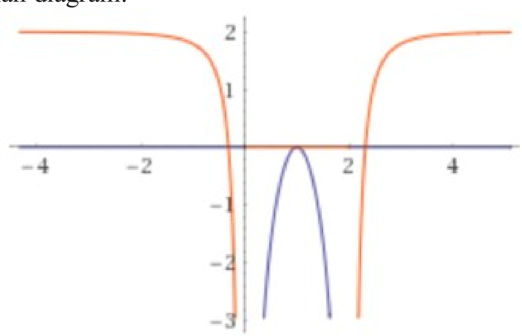

FIGURE 3. Modeling curve K_1

By combining the two curves K_1 and r_n formed from equations (9) and (11) into one cartesian diagram, we find the curve of the front surface of the vehicle was optimal as shown in figure 4.

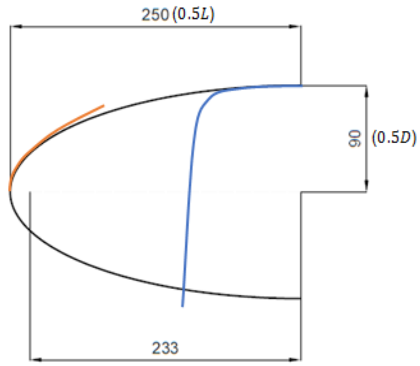

FIGURE 4. Modeling of Front Surface Geometry of the ROV Body Observation Class curve

Figure 4 is the optimization of streamlined geometric curvature in accordance with dimensional ratio of ROV. Parameter of second curvature of curve is shown by curve, equation (9) is shown in orange which represent rn and equation (11) is shown by blue which represent K_1. Both curves are formed by connecting the curves which allow them to be connected to form desired geometry.

REFERENCES

1. F. Aguirre, *State of the Art of Parameters for Mechanical Design of an Autonomous Underwater Vehicle*, Int. J. Ocean. Oceanogr, **11,** 89-113 (2017).
2. H.G. Park, *Hydrodynamic Design of an Underwater Hull Cleaning Robot and Its Evaluation*, Int. J. Nav. Archit. Ocean Eng, **4,** 332–352 (2012).
3. R. Wiryadinata, A. S. Nurliany, I. Muttakin, & T. Firmansyah, *Design of a Low Cost Remotely Operated Vehicle with 3 DoF Navigation*, Bull. Electr. Eng. Informatics **6,** 13–23 (2017).
4. D. Satria, D. P. A. L. Esiswitoyo, N. K. Caturwati, E. Listijorini, & R. Lusiani, *Body Design Concept of Remotely Operated Vehicle (ROV) of Observation Class with the Method of Concept Screening and Concept Scoring*. in MATEC Web Conf. Volume 218, 02009, The 1st International Conference on Industrial, Electrical and Electronics (ICIEE 2018) (2018). doi:https://doi.org/10.1051/matecconf/201821802009
5. J. Parsons, *The Optimum Shaping of Axisymetric Bodies for Minimum Drag in Incompressible Flow*. in Purdue University (1972).
6. P. S. Granville, *Geometrical Characteristic of Streamlined Shapes*, Department of the Navy Naval Ship Research and Development Center (1969).
7. A. Forst, *The Development of a Remotely Operated Vehicle (ROV) for Aquaculture*, Aquac. Eng. **15,** 461–483 (1996).
8. D. L. Paster, *Importance of Hydrodynamic Considerations for Underwater Vehicle Design*, IEEE **86,** 1413–1422 (1986).