Naval Surface Warfare Center
Carderock Division
West Bethesda, MD 20817-5700

NSWCCD-CISD-2011/014 August 2011

Center for Innovation in Ship Design

Technical Report

Hydrodynamic Design Optimization Tool

By

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NSWCCD-CISD-2011/014 August 2011

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
30-08-2011

2. REPORT TYPE
Final

3. DATES COVERED *(From - To)*
05-23-2011 – 30-08-2011

4. TITLE AND SUBTITLE
Hydrodynamic Design Optimization Tool

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Dr. Chi Yang
Devin Bowers

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) AND ADDRESS(ES)
Naval Surface Warfare Center
Carderock Division
9500 Macarthur Boulevard
West Bethesda, MD 20817-5700

8. PERFORMING ORGANIZATION REPORT NUMBER
NSWCCD-CISD-2011/014

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Chief of Naval Research
One Liberty Center
875 North Randolf Street
Suite 1425
Arlington, Va 22203-1995

10. SPONSOR/MONITOR'S ACRONYM(S)
ONR

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
DISTRIBUTION STATEMENT A: Approved for public release; distribution is unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

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15. SUBJECT TERMS
hull form generation, hull form parameters, body plan, Hullgen, CISD

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					Colen Kennell
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			**19b. TELEPHONE NUMBER** *(include area code)*
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR	25	301-227-5468

Abstract

A rapid ship hull form generation tool is developed in support of an ongoing ONR research project on the development of a methodology for innovative hydrodynamic design of ship hull forms. The hull lines/curves in this tool are described by various orders of polynomials and the polynomials are determined using hull form parameters. The hull generation tool is implemented using Matlab to enable graphic user interface. Two hull forms are used for the validation. The present tool is able to generate the same hull forms as the sample hull forms given by Bjorklund & Fuller (1976) with given parameters. This rapid hull form generation tool describes hull form using naval architect's language; generates hull form from scratch in terms of hull form parameters; and establishes the link between the hull form and form parameters. It can be used to generate the hull form for hydrostatic analysis and hydrodynamic design optimization in the early stage of ship design.

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Acknowledgement

The authors would like to acknowledge and thank Colen Kennell, Jack Offutt and Bob Lamb of the Center for Innovation in Ship Design (CISD) for their technical quidence, design insight, support and encouragement. Technical support and administrative help from Steve Ouimette, Livia Cohen, Jeffrey Benson, and the other members of the CISD are greatly appreciated.

The authors would also like to thank David Walden and Francis Noblesse of Code 50 for being instrumental in defining this project, Wesley Wilson of CREATE Program for his support and help on IHDE software.

The work reported here was performed under the ONR-ASEE (American Society of Engineering Education) Summer Faculty Research Program and ONR-ASEE Naval Research Enterprise Intern Program (NREIP). The authors acknowledge the financial and administrative support from the ONR, in particular the support and encouragement from the ONR program director Ms. Kelly Cooper.

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Introduction

Objective

In order to carry out hydrodynamic performance analysis and design optimization in the early stage of ship design, it is essential to have a rapid ship hull form generation tool that can be used to generate hull forms in terms of design needs and hull form parameters. The objective of this project is to develop a rapid hull form generation tool that describes hull form using naval architect's language; generates a hull form from scratch in terms of hull form parameters; and establishes the link between the hull form and form parameters. The tool can be used to define the hull form for hydrostatic analysis and hydrodynamic design optimization in the early stage of ship design.

Background

Hydrodynamic design of ships involves several stages, from early-stage and preliminary design to final design. It has become increasingly important to evaluate multiple hydrodynamic aspects of performance simultaneously and efficiently during the early stage of the design process.

The Computational Fluid Dynamics (CFD) group at George Mason University has an ongoing research project sponsored by the Office of Naval Research (ONR) on the development of a methodology for innovative hydrodynamic design of ship hull forms. The methodology under development will lead to a design tool to explore both conventional and non-traditional hull forms, to define hull forms that exhibit both superior seakeeping and low resistance at early stage of ship design, and to investigate innovative new hull forms with specific design constraints.

In order to apply CFD-based tool to the hydrodynamic design optimization of ship hull forms, an initial hull form is required. The hull surface can then be modified in terms of the design parameters associated with the hull surface representation and modification techniques. Two hull form modification techniques have been developed to obtain maximal benefits from both conventional and parametric modeling techniques (Yang et al., 2008; Kim et al. 2010):

(i) A modified NURBS technique is combined with a parametric global hull modification technique by varying the sectional area curve with a shifting method, in which the design variables in the NURBS technique can be reduced via a grouping method after introducing dependent and independent design variables;

(ii) A radial basis function (RBF) approach is combined with a parametric global hull modification technique by varying the sectional area curve with a shifting method.

The first technique allows for larger variation, and the second one permits the constraints, such as fixed waterline or section shape, to be implemented easily. Figs. 1.1 and 1.2 show the preliminary optimization results of the Series 60 hull model by minimizing the wave resistance using technique (i) for the hull form modification in the optimization process. As it is shown in Fig. 1.1, a new stem profile is generated. Figs. 2.1 and 2.2 show the preliminary bow-region optimization results of the Model 5415 hull by minimizing the wave resistance using technique (ii) for the hull form modification in the optimization process. As it is shown in Fig. 2.1, new sections and profiles are generated. It can be observed from Fig. 1.2 and Fig. 2.2 that both optimal hulls can yield appreciable wave drag reduction.

Initial Hull: Series 60 Hull Model

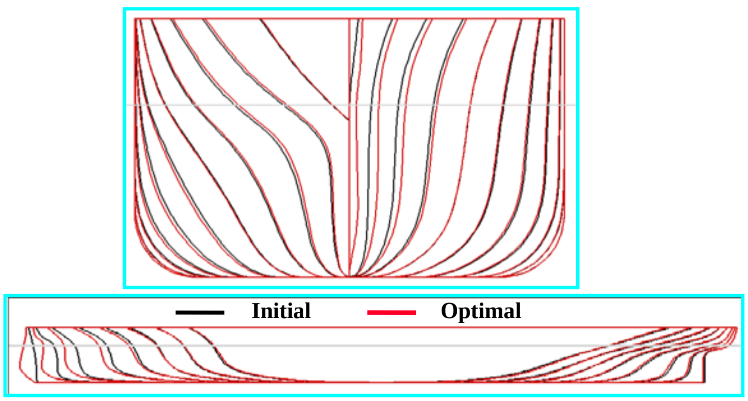


Fig. 1.1 Comparison of the ship lines (sections & profiles)

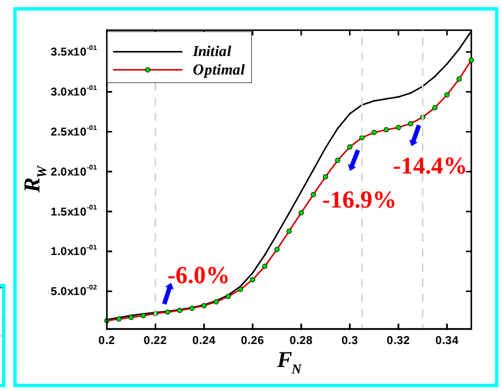


Fig. 1.2 Wave drag reductions at the design speed range

Initial Hull: DTMB Model 5415 Hull

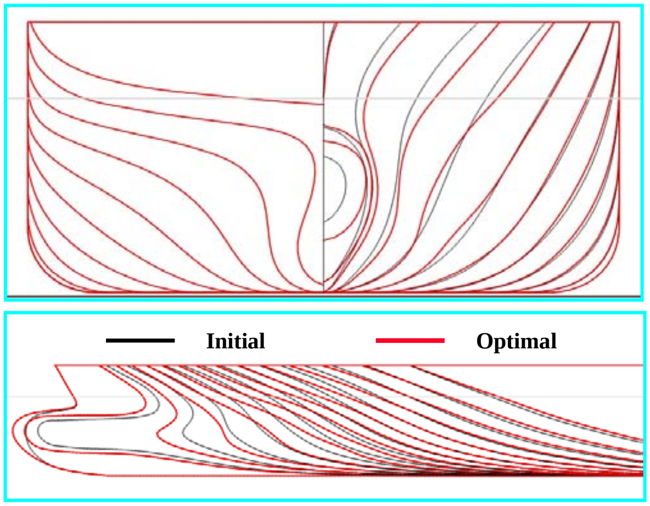


Fig. 2.1 Comparison of the ship lines (sections & profiles)

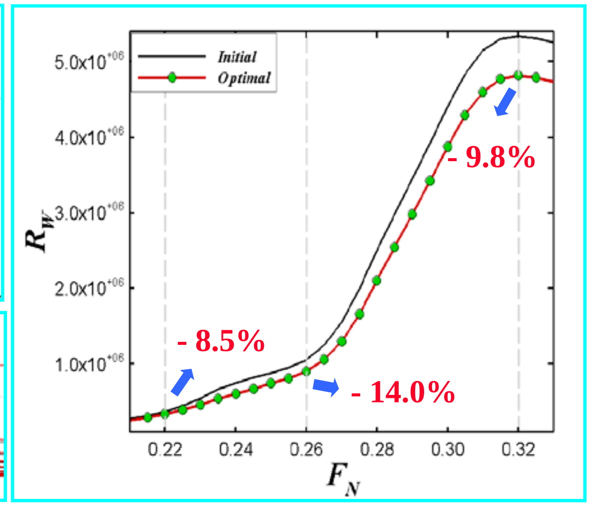


Fig. 2.2 Wave drag reductions at the design speed range

These two combined techniques for hull form modifications have been proven to be very efficient and effective. However, these two techniques would work only in the case that an initial hull form exists. It is of great interest for naval architects to have a rapid hull form generation tool to generate the hull form from scratch using their language, namely in terms of form parameters, and link this tool with the CFD-based hull form optimization tool. An approach given by Bjorklund & Fuller (1976) is adopted in this project to describe the hull lines/curves by various orders of polynomials. The polynomials are determined using hull form parameters. The following sections will discuss the formulation and implementation of the hull generation tool (HullGen_2011) developed in this project.

HullGen_2011

A rapid ship hull form generation tool, HullGen_2011 is implemented using Matlab to enable the graphic user interface. An approach given by Bjorklund & Fuller (1976) is adopted to generate the hull form in terms of the hull parameters. The hull lines/curves are described by polynomials of various orders. The unknown coefficients of the polynomials are determined by the input hull form parameters.

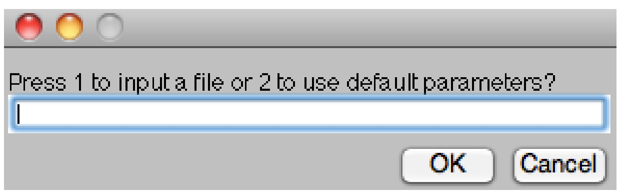
The hull form (body plan) in HullGen is defined in terms of the following control curves:

- Section area curve
- Load waterline curve
- Deck edge curve
- Sheer profile
- Section area coefficient curve

- Keel rise curve
- Section slope curves
- Flat bottom curve

Each curve is defined by a polynomial with a given order. The polynomials are described in a non-dimensional coordinate system, which implies that the coordinates of the polynomials are normalized using different hull parameters. Specifically, x-coordinates (the longitudinal coordinates) are normalized using ½ LPP, the length between forward and aft perpendiculars. The y-coordinates are normalized using different parameters, depending on which curve is being considered.

The computer code HullGen_2011 is written in Matlab. It consists of a main script and a number of functions. The user has the option of either using the default hull form parameters given in the code, or defining them in an input data file. The user can then modify the hull parameters interactively to generate various curves/lines and obtain hull body plan. Two sample input data files are listed in the appendix, which can be used to generate an aircraft carrier type hull form and a destroyer/cruiser type hull form, respectively. The user can type number "1" or "2" in the following prompt box to input the data file or use default hull form parameters after the code HullGen starts to run:



A new prompt box will then be displayed for the user to specify the name of the input data file if the option 2 is selected.

The mathematical formulation of the control curves/hull lines and the user graphic interface prompt boxes displayed with the default hull form parameters are discussed in the following sections.

Section Area Curve

After the user decides to use either default hull form parameters given by the computer code or the hull form parameters specified in the input data file, HullGen will ask for the parameters shown in the following prompt box to generate a section area curve:

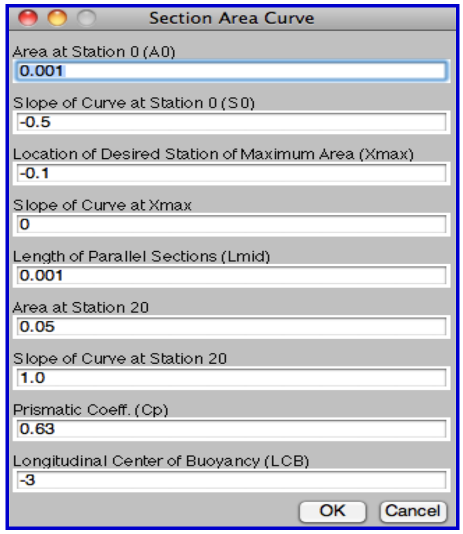


Fig. 3. Prompt box for section area curve

Hereafter, all the graphic user interface prompt box displays the default hull form parameters given in the code.

There are two options to consider for describing the section area curve, one of which is for the hull form without a parallel mid body, the other with a parallel mid body. The coordinates in the section area curve are non-dimensionalized such that the distance from the forward perpendicular (Station 0) to the aft perpendicular (Station 20) makes *x* run from +1.0 to -1.0 with midships (Station 10) at *x*=0. *y*=1 is the ordinate at the station of maximum area.

The following boundary conditions are needed to define the section area curve for the hull form without a parallel mid body:

(1) $x = 1.0,\ y = Area_0$ (Area at Station 0)

(2) $x = 1.0,\ y' = Slope_0$ (Slope of the area curve at Station 0)

(3) $x = x_{\max},\ y = 1.0$ (Location of the station of maximum area)

(4) $x = x_{\max},\ y' = 0.0$ (Slope at the station of maximum area)

(5) $x = -1.0,\ y = Area_{20}$ (Area at Station 20)

(6) $x = -1.0,\ y' = Slope_{20}$ (Slope of the area curve at Station 20)

(7) $\int_{-1}^{1} y dx = 2.0 * C_p$ (Area under the curve defined by the prismatic coefficient C_P)

(8) $\int_{-1}^{1} yx dx = 2.0 * C_p * LCB$ (Centroid of the area under the curve, defined by the longitudinal center of buoyancy *LCB*)

A 7th order polynomial, written as follows, is used to produce the section area curve:

$$y = A_0 + A_1 x + A_2 x^2 + A_3 x^3 + A_4 x^4 + A_5 x^5 + A_6 x^6 + A_7 x^7$$

in which the unknown coefficients A_0 to A_7 are determined by the boundary conditions (1) to (8) described above.

If the user wants to produce a hull with a parallel mid body, a slightly different set of boundary conditions is necessary:

(1) $x = 1.0,\ y = Area_0$ (Area at Station 0)

(2) $x = 1.0,\ y' = Slope_0$ (Slope of the area curve at Station 0)

(3) $x = x_2 = x_{\max} + L_{mid}/2,\ y = 1.0$ (Location of the forward end of the flat section in the area curve)

(4) $x = x_2 = x_{\max} + L_{mid}/2,\ y' = 0.0$ (Slope of the flat section of area curve)

(5) $x = x_1 = x_{\max} - L_{mid}/2,\ y = 1.0$ (Location of the after end of the flat section in the area curve)

(6) $x = x_1 = x_{\max} - L_{mid}/2,\ y' = 0.0$ (Slope of the flat section of area curve)

(7) $x = -1.0,\ y = Area_{20}$ (Area at Station 20)

(8) $x = -1.0,\ y' = Slope_{20}$ (Slope of the area curve at Station 20)

(9) $\int_{-1}^{x_1} y dx + L_{mid} * 1.0 + \int_{x_2}^{1} y dx = 2.0 * C_P$ (Area under the curve, defined by the prismatic coefficient C_P)

(10) $\int_{-1}^{x_1} yx dx + L_{mid} * 1.0 * x_{\max} + \int_{x_2}^{1} yx dx = 2.0 * C_P * LCB$

(Centroid of the area under the curve, defined by the longitudinal center of buoyancy *LCB*)

The above conditions can be used to generate a 9th order polynomial. The section area curve is represented by the 9th order polynomial except the parallel mid body part with a horizontal line of value 1.0. Fig. 4 shows the hull section area curve with a parallel mid body generated using the parameters displayed in Fig. 3.

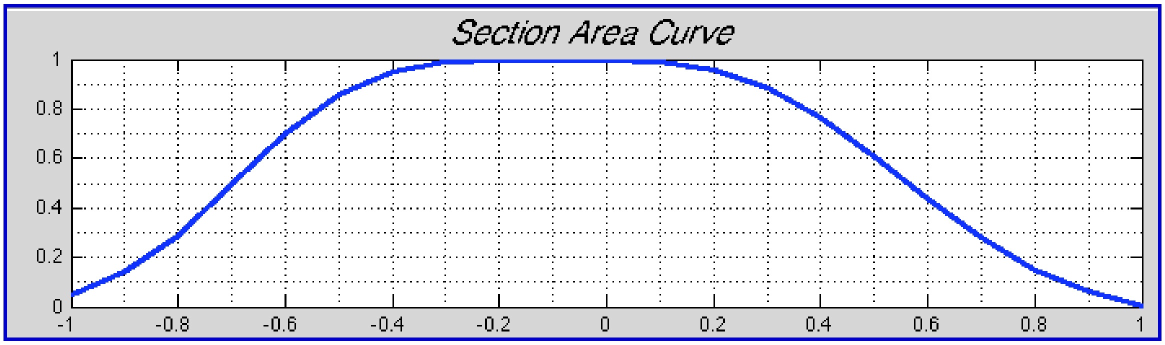


Fig. 4. Hull section area curve with a parallel mid body

Load Waterline Curve

The load waterline curve is a representation of the shape of the hull plan form at the design waterline. The creation of this curve is almost identical to that of the section area curve, except in place of the prismatic coefficient and the longitudinal center of buoyancy, the load waterline curve uses the waterplane coefficient and the longitudinal center of floatation, respectively. The *y*-coordinates are normalized using one half of the ship beam defined at the station of the maximum area.

After HullGen generates the section area curve, it will ask for the parameters shown in the following prompt box to generate a load waterline curve:

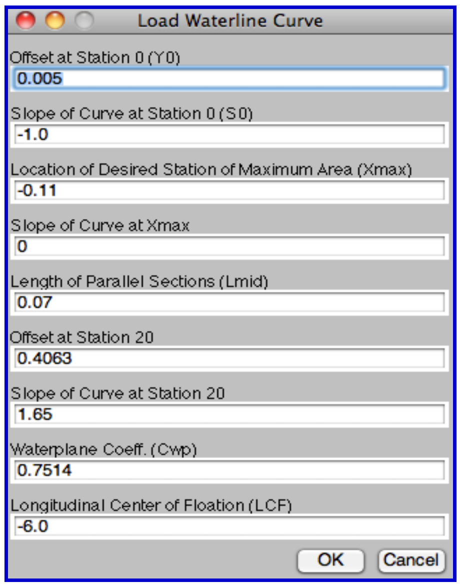


Fig. 5. Prompt box for load waterline curve

As before, there are two options to consider. If the user does not want a parallel mid body, the following are the boundary conditions that the curve should satisfy:

(1) $x = 1.0,\ y = Y_0$ (Offset at Station 0)

(2) $x = 1.0,\ y' = Slope_0$ (Slope of the load waterline curve at Station 0)

(3) $x = x_{max},\ y = 1.0$ (Offset at x_{max} and x_{max} is the station of maximum area from the section area curve. This is where the beam of the ship is defined.)

(4) $x = x_{max},\ y' = Slope\_x_{max}$ (Slope at x_{max} which can be defined so that the beam on the design waterline can be maximum forward of x_{max} , at x_{max} , or aft of

x_{max} . The result is that the actual beam of the ship can be greater than the beam at the station of maximum area)

(5) $x = -1.0,\ y = Y_{20}$ (Offset at Station 20)

(6) $x = -1.0,\ y = Slope_{20}$ (Slope of the load waterline curve at Station 20)

(7) $\int_{-1}^{1} ydx = 2.0 * C_{WP}$ (Area under the curve, defined by the waterplane coefficient C_{WP})

(8) $\int_{-1}^{1} yxdx = 2.0 * C_{WP} * LCF$ (Centroid of the area under the curve, defined by longitudinal center of floatation LCF)

The above boundary conditions can be used to create a 7th order polynomial to represent the load waterline curve for the hull that does not have a parallel mid body. However, if the user wants to design a hull with a parallel mid body, a slightly different set of boundary conditions is required:

(1) $x = 1.0,\ y = Y_0$ (Offset at Station 0)

(2) $x = 1.0,\ y' = Slope_0$ (Slope of the load waterline curve at Station 0)

(3) $x = x_2 = x_{max} + L_{mid}/2,\ y = 1.0$ (Offset at forward end of parallel section)

(4) $x = x_2 = x_{max} + L_{mid}/2,\ y' = 0.0$ (Slope of parallel section)

(5) $x = x_1 = x_{max} - L_{mid}/2,\ y = 1.0$ (Offset at after end of parallel section)

(6) $x = x_1 = x_{max} - L_{mid}/2,\ y' = 0.0$ (Slope of parallel section)

(7) $x = -1.0,\ y = Y_{20}$ (Offset at Station 20)

(8) $x = -1.0,\ y = Slope_{20}$ (Slope of the load waterline curve at Station 20)

(9) $\int_{-1}^{x_1} ydx + L_{mid} * 1.0 + \int_{x_2}^{1} ydx = 2.0 * C_{WP}$ (Area under the curve, defined by the waterplane coefficient C_{WP})

(10) $\int_{-1}^{x_1} yxdx + L_{mid} * 1.0 * x_{max} + \int_{x_2}^{1} yxdx = 2.0 * C_{WP} * LCF$
(Centroid of area under the curve, defined by the longitudinal center of floatation LCF)

The above boundary conditions can be used to generate a 9th order polynomial. The load waterline curve is represented by the 9th order polynomial except the parallel mid body section of the curve with a horizontal line of value 1.0. Fig. 6 shows the load waterline curve with a parallel mid body generated using the parameters displayed in Fig. 5.

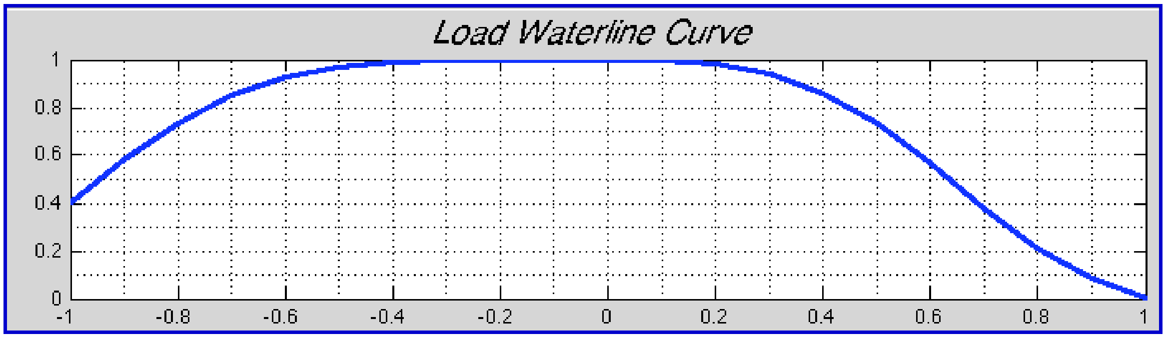


Fig. 6 Load waterline curve with a parallel mid body

Deck at Edge Curve

The deck at edge curve represents the shape of the deck. This curve is created by combining three curves: i) a 3rd order polynomial for the curve forward of a flat middle section; ii) a straight line for the middle section if any; and iii) a 3rd order polynomial for the curve aft of the flat middle section. The *y*-coordinates are normalized using half of the ship beam defined at the station of the maximum area.

After the HullGen generates the load waterline curve, it will ask for the parameters shown in the following prompt box to generate a flush deck at edge curve:

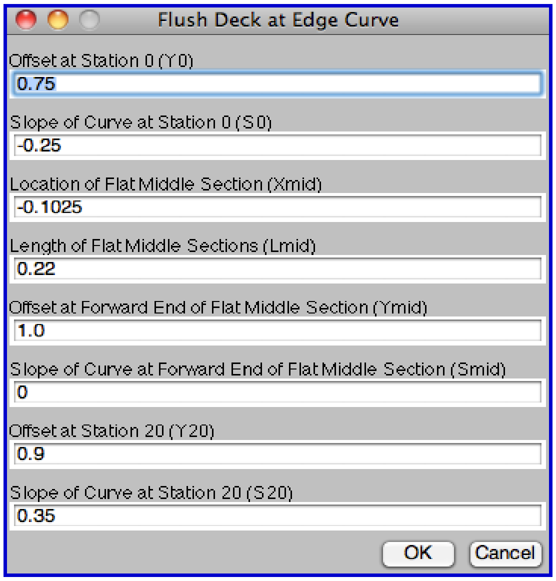


Fig.7. The prompt box for the flush deck at edge curve

To create the forward section of the flush deck at edge curve, the following boundary conditions must be satisfied:

(1) $x = 1.0,\ y = Y_0$ (Offset at Station 0)

(2) $x = 1.0,\ y' = Slope_0$ (Slope of the flush deck at edge curve at Station 0)

(3) $x = x_2,\ y = Y_{MID}$ (Offset at forward end of flat middle section defined by L_{MID} and x_{MID})

(4) $x = x_2,\ y' = 0$ (Zero slope by definition)

The above conditions can be used to generate a 3rd order polynomial for the forward section. Note how there are no coefficients to govern the shape of the curve. The aft portion of the curve is formulated in a similar manner as above. Fig. 8 shows a flush deck at edge curve generated using the parameters displayed in Fig. 7.

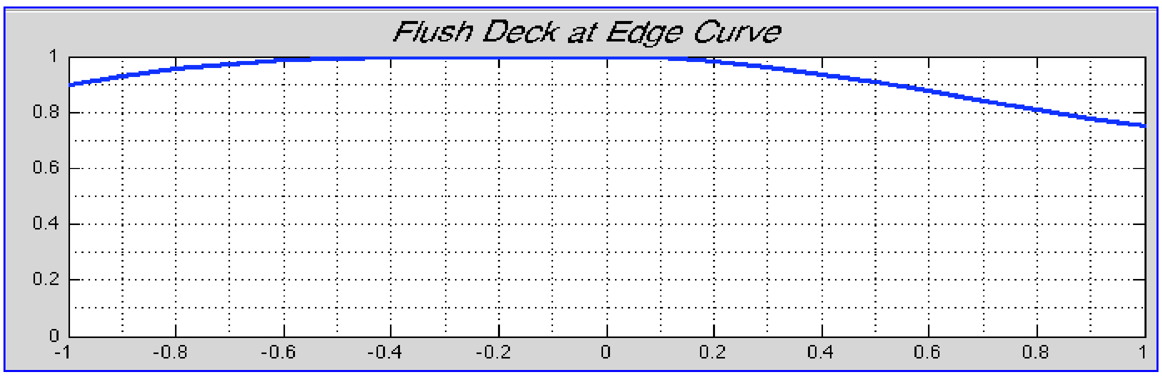


Fig. 8. Flush deck at edge curve

Sheer Profile

The sheer profile defines the depths at various points, which also defines the heights of the deck at every section. To generate this curve, the user inputs the depths at Stations 0, 10, and 20. With these boundary conditions, HullGen generates a 2nd order polynomial. This curve is dimensionalized, i.e. the user inputs the **actual values** of the depths instead of relative values. Fig. 9 shows the prompt box for the sheer profile. The sheer profile generated using the parameters displayed in Fig. 9 is plotted in Fig. 10.

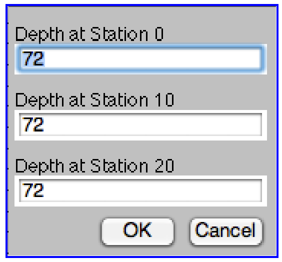


Fig. 9. The prompt box for sheer profile

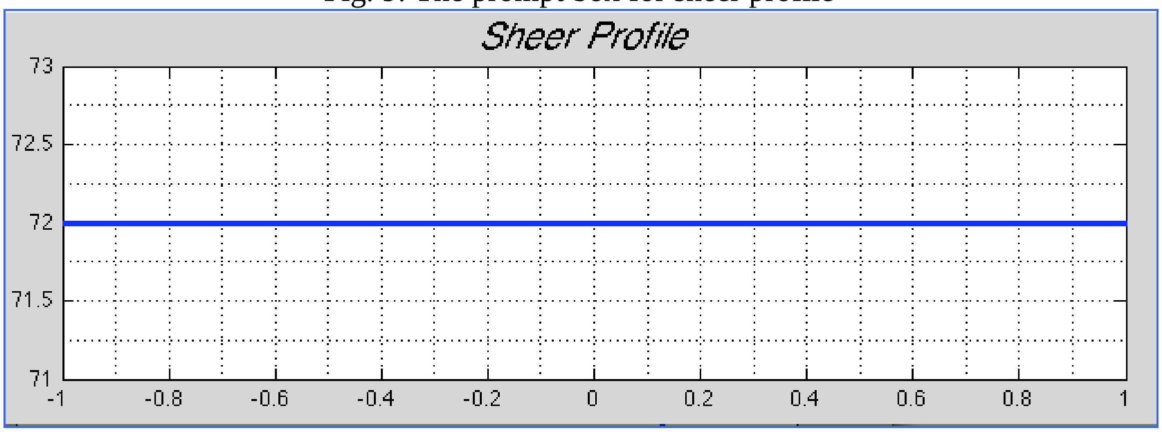


Fig. 10. Sheer profile curve

Keel Rise Curve

The keel rise curve describes the shape of the keel of the ship as viewed from the side. To generate this curve, HullGen must first calculate the section coefficient curve, which is defined as the local area of the station divided by the local beam on the design waterline and local draft as follows:

$$C_I(x) = \frac{SA(x) * C_X}{DWL(x)}$$

where *SA(x)* is local section area curve, C_X is maximum section area coefficient, and *DWL(x)* is local beam. When calculating this curve, the user assumes an initial non-dimensional constant draft of value 1. The user can then enter in their desired position where the keel will begin to rise, as well as a desired section coefficient at Station 20, C_{I_20} , which is shown in the following prompt box:

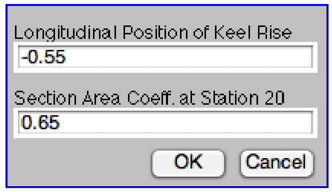


Fig. 11. The prompt box for keel rise curve

Fig. 12 shows two section coefficient curves. The lower curve in Fig. 12 represents the section coefficient curve if no keel rise is allowed. The upper curve in Fig. 12 is faired section coefficient curve with keel rise. It should be noted that the upper curve is faired into the section coefficient curve at the station of keel rise by matching the ordinate and the slope of the curve at this point. The curve goes through the selected section coefficient at Station 20. These three boundary conditions are used to generate a 2nd order polynomial that is plotted as an upper curve in Fig. 12.

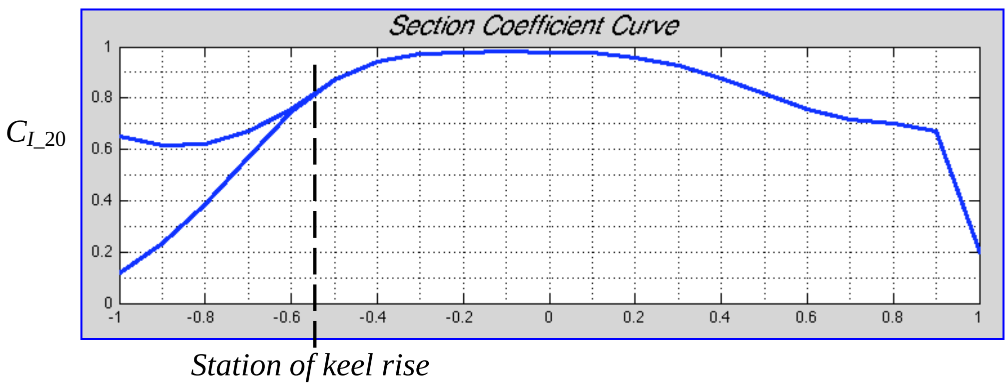


Fig. 12. Section coefficient curve

With this new section coefficient curve, the draft at each position can be recalculated as follows:

$$H(x) = \frac{SA(x) * C_X}{DWL(x) * C_I(x)}$$

which can be used to generate the keel rise curve shown in Fig. 13.

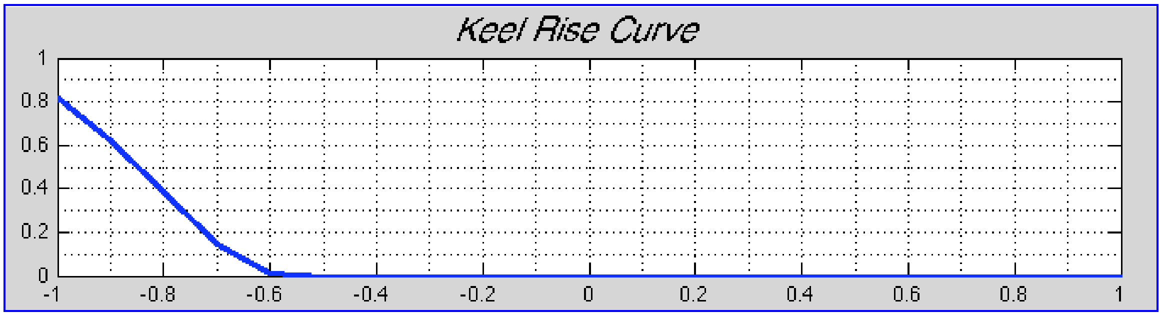


Fig. 13. Keel rise curve

Flat of Bottom Curve

The flat of bottom curve provides the user with an outline of which portions of the bottom of the ship is flat or completely horizontal. It also determines which of the side hull sections can be created with a polynomial representation or a full section representation with a radius of curvature.

The curve is split into five sections:

I. $x_1 \le x \le 1.0$

This section represents the forward-most section of the flat of bottom curve. x_1, the start of the flat bottom curve and the slope at x_1 are user defined. The y value forward of x_1 is equal to the halfsiding selected. The halfsiding is faired to zero forward to station 0.

II. $x_2 \le x \le x_1$

This curve is represented by a 3rd order polynomial defined by the y_1 at x_1, y_2 at x_2, and the slopes at these points. The slope at x_2 is calculated and is not user specified.

III. $x_3 \le x \le x_2$

The location of x_2 and x_3 are user defined and thus determine the extent over which full sections will be used in the body plan. Thus y_2 and y_3, and the slopes of the curve at these points are calculated. For the full section, we have

$$y = DWL(x) - \frac{R}{B_X / 2}$$

and

$$R = \left[\frac{H_X * B_X * 1/2 * \left(DWL(x) - SA(x) * C_X \right)}{1 - \pi / 4} \right]^{1/2}$$

where

$C_X =$ maximum section coefficient
$B_X =$ maximum section beam
$H_X =$ maximum section draft
$DWL(x) =$ load waterline offset as a function of x
$SA(x) =$ section area as a function of x

IV. $x_4 \le x \le x_3$

Similar to Section II above.

V. $-1 \le x \le x_4$

Similar to Section I above.

The parameters used to determine the flat bottom curve are defined in the prompt box shown in Fig. 14. The flat bottom curve can then be obtained by combine five curves described above. Fig. 15 shows the flat bottom curve and load waterline curve, respectively.

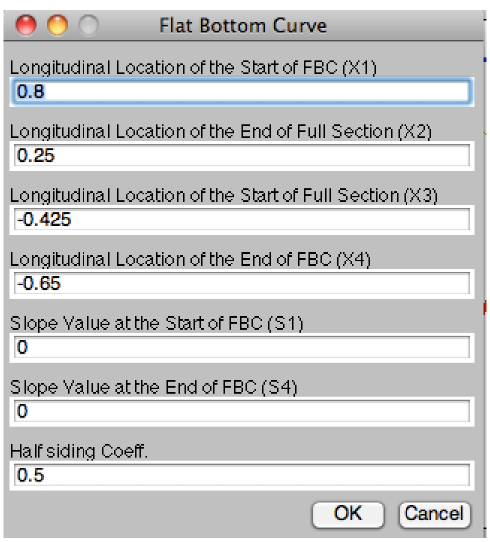


Fig. 14. Prompt box for flat bottom curve

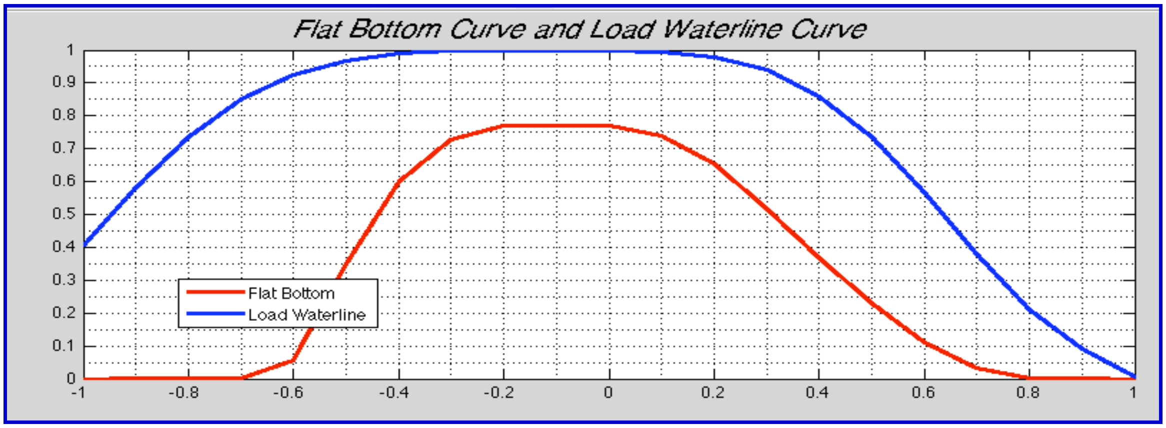


Fig. 15. Flat bottom curve and load waterline curve

Slope Curves

In order to assure reasonable longitudinal fairness in the hull form being produced, controls are placed on the longitudinal variation of the slopes that define the section shapes at deck at edge, design waterline and keel, thus three slope curves: keel slope, waterline slope, and deck slope.

All three curves are implemented in the same manner: two 3^{rd} order polynomials connected with a flat middle section. For each polynomial, the user inputs the necessary boundary conditions for the end points of each 3^{rd} order polynomial. The user also inputs the length of the flat middle section, as well as the center point at which the middle of the flat section occurs. Each curve is generated using a very similar method to that of the deck at edge curve. Fig. 16 shows the prompt box for these three slope curves, and Fig. 17 shows the three slope curves generated using the parameters specified in the prompt box shown in Fig. 16.

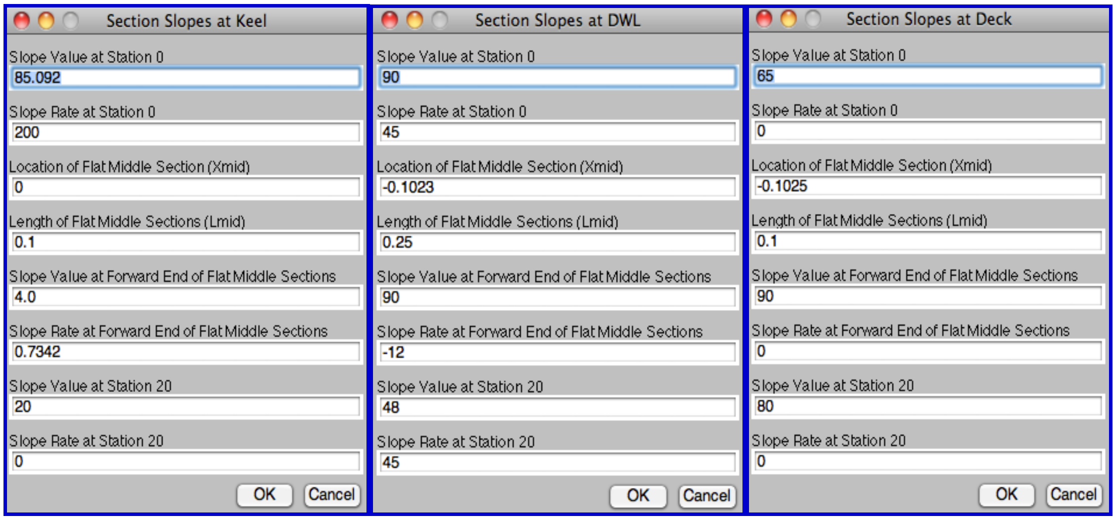


Fig. 16. Prompt box for section slope curves

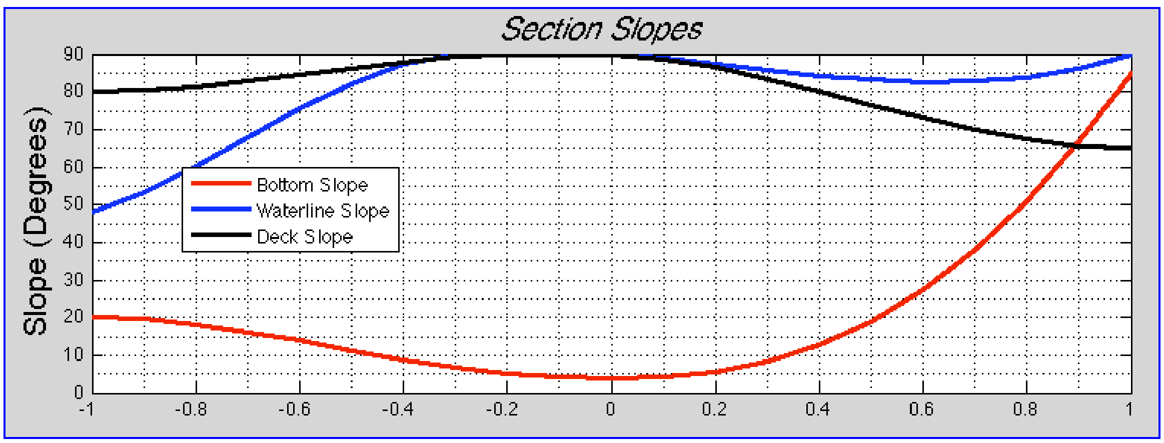


Fig. 17 Section slopes vs longitudinal location

Body Plan

The following curves were designed with a flipped axis, i.e. the x-axis is vertical and the y-axis is horizontal. This allows for HullGen to create vertical hull sides that would otherwise be impossible to generate.

<u>Fine Sections (Below Load Waterline)</u>

The fine section is one method of creating a hull side underwater. It is narrow and has a more triangular shape than the full section, which will be discussed later on. This curve is normalized using the local beam and the local draft.

The following boundary conditions have to be satisfied:

(1)	$x = 0.0,\ y = HS$	(Half siding (HS) is the normalized half siding of the keel plate. This offset can also be the result of a flat bottom requirement)
(2)	$x = 0.0,\ y' = Dead\ Rise\ Slope$	(Dead rise curve is user defined from the keel slope curves. This value must be great than 0)
(3)	$x = 1,\ y = 1.0$	(By definition)
(4)	$x = 1,\ y' = slopeDWL$	(Slope of the section at the design waterline as defined by the slope curve)
(5)	$\int_0^1 ydx = Area$	(Required area as defined by the sectional area curve)

Instead of using a regular 4th order polynomial for above boundary conditions, the the following polynomial better fit the required shape (Bjorklund and Fuller, 1976):

$$y = A_0 x^2 + A_1 x + A_2 + A_3 (x+1)^{-2} + A_4 (x+k))^{1/2}$$

The constant k was an arbitrary value to avoid undefined results, which may occur when dealing with derivatives. We used the value k = 0.0001 in the HullGen 2011 program. Fig. 18 shows the fine body section below load waterline in a normalized coordinate system.

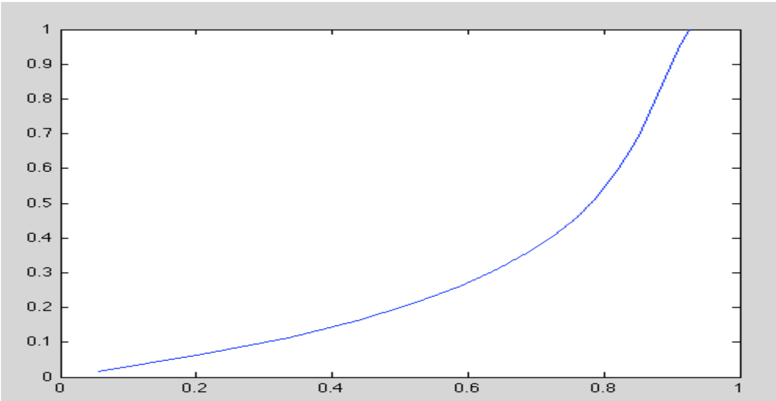


Fig. 18 Fine body section (below waterline)

<u>Fine Sections (Above Load Waterline)</u>

The coordinate system is the same as the ones used for the hull shape. We can also use fine sections to create the hull shape above water. These are calculated using the beam width, as well as using the difference between the sheer profile and the draft. Thus, this curve is dimensionalized, but it has also been translated by the draft.

The boundary conditions for this curve are:

(1)	$x = 0,\ y = 0$	(Results of normalization)
(2)	$x = 0,\ y' = slope\,DWL$	(This slope is the same as used at the DWL for the section below the DWL)
(3)	$x = x_1,\ y = y_1$	(Local depth and beam obtained)
(4)	$x = 0,\ y' = slope\,Deck\,at\,edge$	(Flare slope is derived from the slope curve of the section at the design waterline)

With these boundary conditions, the above water hull side can be represented using a 3rd order polynomial. Fig. 19 shows the fine body section above load waterline with actual values.

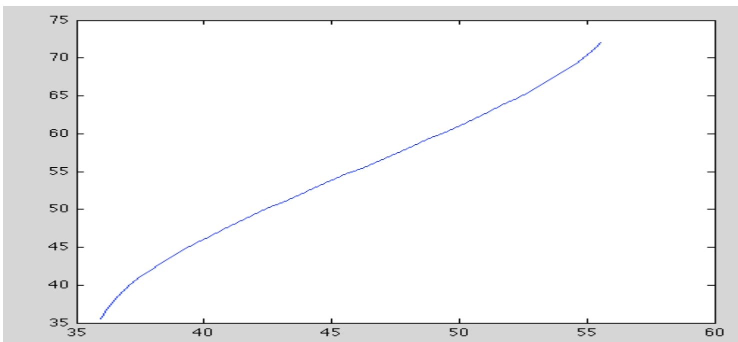


Fig. 19 Fine body section (above waterline)

<u>Full Sections</u>

Full sections are characterized by having a flat bottom and vertical sidewall, connected by a quarter circle with a constant radius. To create this curve, we cannot use non-dimensionalized coordinates due to distortions of the curve creating an elongated hull.

HullGen first calculates the radius of the hull using the formula:

$$R = sqrt\left(\left(H(x) * B(x) - Area(x)\right) / \left(1 - \pi / 4\right)\right)$$

where *H(x)* is actual draft at particular station (feet), *B(x)* actual offset at particular station (feet), and *Area(x)* actual area of station as derived from section area curve. With *R* known, the offsets are calculated as:

$$y = B(x) - R + \sqrt{2 * R * x - x^2}, \quad \text{for } 0 \le x < R$$
$$y = B(x), \quad \text{for } x \ge R$$

It is just as easy to create the above water hull sides using the same algorithm as these with the fine section hulls; the result will be a flat line to correspond with the flat side of the hull. The full body section based on previous curves is shown in Fig. 20.

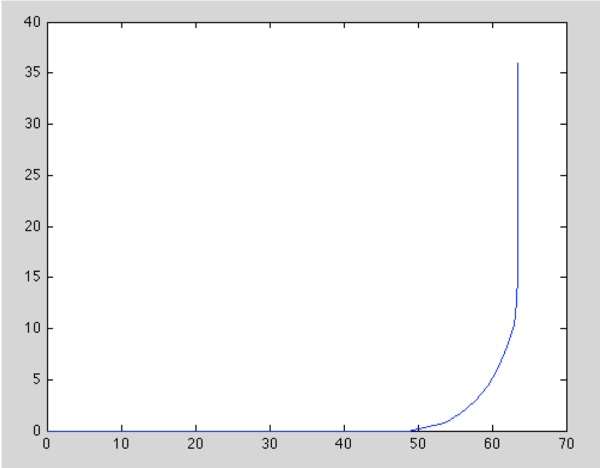


Fig. 20 Full body section

Final Body Profile

With all of these polynomials generated, HullGen combines them to create a body profile. The user has options. They can plot a 3D hull surface or body profiles by combing the polynomials below and above load waterline.

To ensure that both the methods developed by Bjorklund and Fuller (1976) were accurate, as well as verify our own code, we used sample parameters presented in the previous sections to create an aircraft carrier type ship. The polynomial representation of the carrier body profile is shown in Fig. 21.

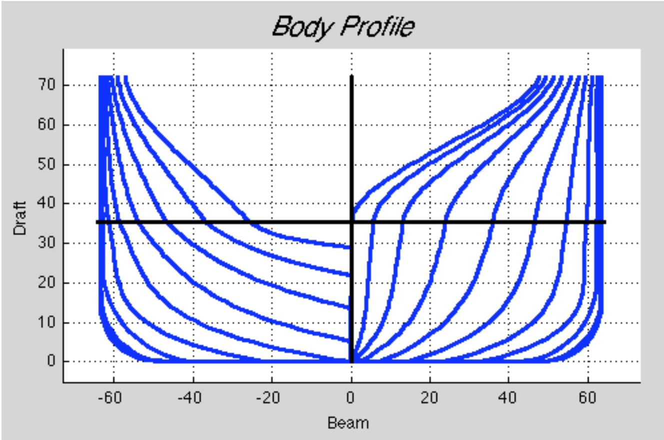


Fig. 21. Body profile of a carrier

HullGen has also been used to create a destroyer/cruiser type hull with the data file shown in appendix. The body profile is shown in Fig. 22.

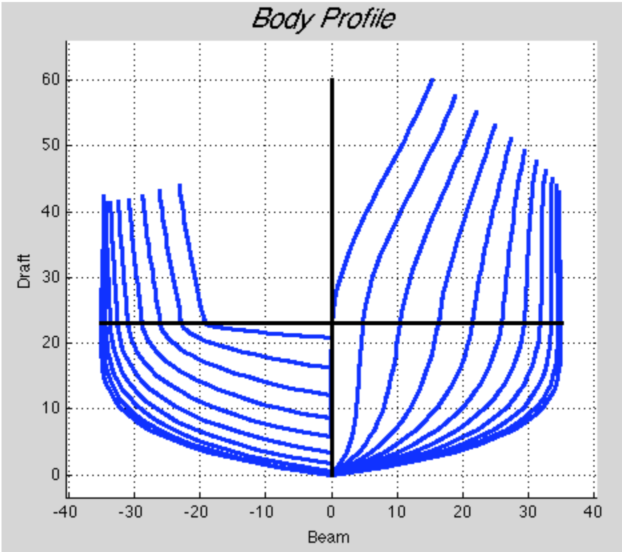


Fig. 22. Body profile of a destroyer/cruiser type hull

Conclusions

A rapid ship hull form generation tool is developed and validated. The hull lines/curves in this tool are described by polynomials of various orders and the polynomials are determined using the hull form parameters. The hull generation tool is implemented using Matlab to enable graphic user interface. The present tool is able to generate the same hull forms as the sample hull forms given by Bjorklund & Fuller (1976) with given parameters. This rapid hull form generation tool describes hull form using naval architect's language; generates hull form from scratch in terms of hull form parameters; and establishes the link between the hull form and form parameters. It can be used to generate the hull form for hydrostatic analysis and hydrodynamic design optimization in the early stage of ship design.

Future work will be centered on comparing the seakeeping results obtained using the exact stations and the approximate stations generated using HullGen. The HullGen will also be used to generate various hull forms and for optimization.

References

Bjorklund, F.R. and Fuller, A.L. "Ship Hull Form Generation Using Interactive Graphics," presented to The Chesapeake Section of SNAME, May 1976, Washington D.C.

Fuller, A.L. "User Guider to Interactive Lines Generation (HULGEN) with a Storage Tube," Proceedings of the REAPS Technical Symposium, June 1978, St. Louis, Missouri.

Kim, H.Y., Yang, C. and Noblesse, F. "Hull Form Optimization for Reduced Resistance and Improved Seakeeping via Practical Designed-Oriented CFD Tools," Proceeding of the Grand Challenges in Modeling & Simulation (GCMS'10), Ottawa, Canada, July 11-14, 2010, pp. 375-385.

Yang, C., Kim, H.Y., Löhner, R. and Noblesse, F. "Practical Hydrodynamic Optimization of Ship Hull Forms," Proceeding of the Grand Challenges in Modeling & Simulation (GCMS'08), Edinburgh, UK, June 16-19, 2008, pp. 435-444.

Appendix

The following table shows the sample input data file for generating the body profile of a destroyer/cruiser type hull shown in Fig. 22, and the body profile of a carrier shown in Fig. 21.

Input data for a destroyer/cruiser shown in Fig. 22	Input data for a carrier shown in Fig. 21
MainParameters numStations 20 Length 600 Beam 70 Draft 23 maxCoeff 0.82 numSegments 20 SectionAreaCurve A0 0.0 S0 -1.123 Xmax -0.052 Smax 0 Lmid 0 A20 0.04 S20 0.9718	MainParameters numStations 20 Length 925 Beam 127 Draft 35.5 maxCoeff 0.98 numSegments 40 SectionAreaCurve A0 0.001 S0 -0.5 Xmax -0.1 Smax 0 Lmid 0.001 A20 0.05 S20 1.0

Cp 0.62	Cp 0.63
LCB -1	LCB -3
DesignWaterline Y0 0.005	DesignWaterline Y0 0.005
S0 -1.08	S0 -1.
Xmax -0.052	Xmax -0.11
Smax -0.025	Smax 0
Lmid 0	Lmid 0.07
Y20 0.55	Y20 0.4063
S20 1	S20 1.65
Cwp 0.76	Cwp 0.7514
LCF -5.5	LCF -6.0
DeckEdge Y0 0.436	DeckEdge Y0 0.75
S0 -1.0649	S0 -0.25
Xmid -0.1025	Xmid -0.1025
Lmid 0.22	Lmid 0.22
Y10 0.989	Y10 1.0
S10 -0.06103	S10 0

Y20 0.6592 S20 0.9427 Sheer D0 60 D10 43 D20 44 Drafts keelPos -0.15 coeff20 0.65 BottomSlope T0 70 S0 240 Xmid -0.052 Lmid 0 T10 4 S10 6.547 T20 1.4474 S20 20 waterlineSlope T0	Y20 0.9 S20 0.35 Sheer D0 72 D10 72 D20 72 Drafts keelPos -0.55 coeff20 0.65 BottomSlope T0 85.092 S0 200 Xmid 0 Lmid 0.1 T10 4.0 S10 0.7342 T20 20 S20 0 waterlineSlope T0

88 S0 35 Xmid -0.052 Lmid 0 T10 90 S10 0 T20 77.968 S20 20 deckSlope T0 69 S0 -10 Xmid -0.052 Lmid 0 T10 89 S10 -10 T20 84 S20 0 flatBottom X1 -0.15 X2	90 S0 45 Xmid -0.1023 Lmid 0.25 T10 90 S10 -12 T20 48 S20 45 deckSlope T0 65 S0 0 Xmid -0.1025 Lmid 0.1 T10 90 S10 0 T20 80 S20 0 flatBottom X1 0.8 X2

-0.15 X3 -0.15 X4 -0.15 S1 0 S4 0 HS 0.5	0.25 X3 -0.425 X4 -0.65 S1 0 S4 0 HS 0.5