Hull Shape Optimization for Wave Resistance Using Panel Method

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Hull Shape Optimization for Wave Resistance Using Panel Method

A Thesis

Submitted to the Graduate Faculty of the University of New Orleans in partial fulfillment of the requirements for the degree of

Master of Science in Engineering Naval Architecture and Marine Engineering

by

Krishna Murthy Karri

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Dedication

I would like to dedicate this thesis to my parents and brother for all of their love and support.
Acknowledgments

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Nomenclature

$\alpha$  fraction for raise of free surface panels

$\bar{x}$  centroid of half body as a fraction of halflength

$\bar{z}$  LCB as a percentage of length

$\delta \bar{z}$  required shift of LCB as a percentage of length

$\delta \phi_a$  required change in prismatic coefficient of afterbody

$\delta \phi_f$  required change in prismatic coefficient of forebody

$\delta \phi_t$  required change in total prismatic coefficient

$\delta p_a$  required change in length of aft parallel middle body

$\delta p_f$  required change in length of forward parallel middle body

$\delta x_a$  resultant longitudinal shift of aft section at $x_a$

$\delta x_f$  resultant longitudinal shift of forward section at $x_f$

$\phi$  prismatic coefficient of half body

$\phi_t$  total prismatic coefficient

$A$  Lackenby constants for half body

$A_a$  Lackenby constants for afterbody

$A_f$  Lackenby constants for forebody

$B$  Lackenby constants for half body

$B_a$  Lackenby constants for afterbody

$B_f$  Lackenby constants for forebody

$C$  Lackenby constants for half body

$C_a$  Lackenby constants for afterbody
\(C_f\) Lackenby constants for forebody

\(k\) lever of the second moment of the original SAC about midships

\(LCB\) Longitudinal center of buoyancy from origin

\(p\) fractional length of parallel middle body of halflength

\(p_a\) fractional length of parallel middle body of afterbody

\(p_f\) fractional length of parallel middle body of forebody

\(SAC\) sectional area curve

\(x_a\) co-ordinates from midhips to the aft end

\(x_f\) co-ordinates from midhips to the forward end

\(C_m\) midship sectional area coefficient

\(C_p\) prismatic coefficient
Abstract

A ship must be designed for efficiency and economy; thus there is an everlasting desire for the design of better and better ships. One of the important factors which directly influence the worthiness of a design is its resistance. Throughout decades of ship design, the resistance is given top most importance as a design objective. With the increase in computational speeds of both software and hardware, there has been an opportunity for optimizing ship hulls using iterative methods of design and modification.

A method for calculating resistance for a given hull geometry and to optimize it using optimization algorithms are required for achieving better hulls. The resistance is calculated using a panel method for a given hull and the hull geometry is later changed by applying Lackenby’s method of longitudinal shift of stations.

An optimization algorithm extracts the best possible design out of the numerous design alternatives possible.

Keywords: Resistance, Panel Method, Lackenby Transformation, Optimization, Longitudinal Center of Buoyancy
Chapter 1

Introduction

Development of new hull shapes is based on a number of coupled characteristic features. They determine both technological and economic worthiness of a design. The development of a new hull, in general, can be approached in three different ways:

- Hull form from standard series.
- Form parameter based hull design.
- Hull form generation based on parent ship data.

Hull form design based on standard series are derived from empirical data, such as Todd’s Series 60 [2], Taylor Standard Series [16], BSRA [7], MARAD [13] and Ridgley-Nevitt [12], resulted from model tests carried out in model basins. The individual models have been derived from a parent hull by systematic variation of geometric parameters. In many of the standard series length to beam ratio (L/B) and beam to draft ratio (B/T) have been varied. Various methods have been proposed to select a hull form from the standard series data. One of them is to select preliminary dimensions based on parent ship analysis. Parent ship analysis is a deterministic approach where a new hull is selected by using regression analysis on the available parent hull data. However, each of these series are developed for a specific type of vessel, thus making it difficult to achieve modern hull forms using series data.
Form parameter based hull design starts with a very basic approach of using a small number of control parameters for attaining final design requirements. The basic hull properties, such as center line buttock or the shape of the deck profile for example, are defined by curves created from form parameters. Once this set of basic hull curves is created from the control parameters, a numerical algorithm is applied to create a set of sections at selected locations. This is achieved by utilizing a parametric curve generation process where the vertices of all B-spline curves are computed from a geometric algorithm, which solves for a required fairness criteria and a global shape constraints [17]. As the design is completely based on the input form parameters, it may sometimes lead a designer into a techno-economically bad design. Better hull forms can be generated by incorporating a design optimization method within this design sequence.

The third alternative for designing hull forms is based on modifying an existing hull form. This method gives a partial confidence to the designer right from the beginning as he starts from a design which already performed well in real time. The selection of parent hull form is based on a preliminary analysis of available vessels which are close to the desired hull form with good design objectives. Even though the design is based on better parent hull forms, they have to be optimized for the changes in operational conditions. For a ship hull to be qualified as a good design, it has to meet the requirements such as minimal propulsion power, maximum internal volume, maximum stability, ease of construction etc. [8].

1.1 Purpose, Motivation and Objective of Study

The rising demand for better transportation and latest development in computing power has provided an opportunity to give automated design and optimization a thought. Efficient transportation by sea plays a vital role in intercontinental trade. So for future transportation we need a good design and optimization methods for achieving reliable hull forms. The preliminary design of hull form has already taken a strong form, with a very little scope to
get better, whereas the optimization is the one which is yet to be developed for reliability and validity. Thus a major consideration is given to the hull form optimization in present work.

In the present work, a design optimization method is developed by taking a standard hull of a KRISO container ship, provided by Korea Research Institute for Ships and Ocean Engineering [14], and is used as a baseline model for verifying the results.

1.2 Proposed Method

The method comprises of geometry acquisition, panel generation, panel method for resistance computation and the optimization. The process of hull optimization using a panel method definitely requires a programming language with a higher computational power and a good structure. To achieve the best out of available resources, FORTRAN is used for numerical operations of panel method and PYTHON is used for reading geometry, panel generation and integrating the process of optimization.

To make the process more generic, the hull geometry is considered as a standard GHS geometry file format. This file typically contains markers which specify the sections of a hull. The marker data is converted to a panel file using a shape function for panel distribution. The aspect ratio of hull panels is also a significant factor contributing to the accuracy of the panel method. The frictional resistance component remains almost the same and the major component to be minimized, is the wave making resistance. The wave making resistance is calculated by integrating the pressure distribution over wetted surface of the hull. It is used as objective function in the optimization. The simple yet efficient Nelder-Mead simplex algorithm is used for optimizing the hull for a better performance. The hull shape is varied using the Lackenby [5] transformation respective to a change in LCB position.

At the end of the optimization process, the hull is iterated to reach an optimum LCB position for which it has the least wave making resistance.
Chapter 2

Background

2.1 Geometrical Variation of Ship Hull Forms

H. Lackenby [5] proposed a method of designing a new vessel by systematic geometric variation of a parent ship form. His alternative to the “one minus prismatic” method varies the hull form with more control on design parameters. The “one minus prismatic” has a few limitations for achieving control over the independent variation of prismatic coefficient and parallel middle body, as well as restrictions on variation of fullness, entrance, run and maximum longitudinal shift of sections [5]. Lackenby’s method allows to modify fullness, longitudinal position of buoyancy, and the extent of parallel middle in both fore and after bodies independently i.e. the variation can be carried in one or all of the above parameters at a time. The method is as follows,

Lackenby Transformation

Many design evaluation methods, such as resistance calculation techniques, use the major shape parameters of the hull to calculate their results. These parameters typically include length, beam, draft, prismatic coefficient (Cp), longitudinal center of buoyancy (LCB), and amidships coefficient (Cm). It is difficult to perform parametric or sensitivity studies using these techniques because all of the variables are interrelated and may change at the same
time. For example, when a vessel’s length is varied, it’s Cp, LCB and displacement values change at the same time. It would be desirable to be able to change any one of these major design variables, while maintaining constant values for the rest. Of course, this is impossible, because as one variable changes, at least one other variable must change to compensate. In the present approach Lackenby method for my hull variation is used. This method used the sectional area curve and allows for the modification of the following parameters The following form parameters are varied. They are

- Prismatic coefficient (Cp)
- Longitudinal center of buoyancy (LCB)
- Parallel middle body - forward (pf)
- Parallel middle body - aft (pa)

\[
\delta \phi_f = \frac{2[\delta \phi_t (B_a + \bar{z}) + \delta \bar{z} (\phi_t + \delta \phi_t)] + C_f \cdot \delta p_f - C_a \cdot \delta p_a}{B_f + B_a} \tag{2.1}
\]

\[
\delta \phi_a = \frac{2[\delta \phi_t (B_f - \bar{z}) - \delta \bar{z} (\phi_t + \delta \phi_t)] - C_f \cdot \delta p_f + C_a \cdot \delta p_a}{B_f + B_a} \tag{2.2}
\]

For a required change in hull form, the sectional area distribution is changed. The necessary change in station spacing is given by \( \delta x_f \) for stations forward of midships and by \( \delta x_a \) for stations aft of midships.

\[
\delta x_f = (1 - x_f) \left\{ \frac{\delta p_f}{1 - p_f} + \frac{(x_f - p_f)}{A_f} \left[ \delta \phi_f - \delta p_f \left( \frac{1 - \phi_f}{1 - p_f} \right) \right] \right\} \tag{2.3}
\]

\[
\delta x_a = (1 - x_a) \left\{ \frac{\delta p_a}{1 - p_a} + \frac{(x_a - p_a)}{A_a} \left[ \delta \phi_a - \delta p_a \left( \frac{1 - \phi_a}{1 - p_a} \right) \right] \right\} \tag{2.4}
\]
Where, the constants A, B and C are given by,

\begin{align*}
A &= \phi (1 - 2\bar{x}) - p (1 - \phi) \quad (2.5) \\
B &= \frac{\phi [2\bar{x} - 3k^2] - p (1 - 2\bar{x})}{A} \quad (2.6) \\
C &= \frac{B (1 - \phi) - \phi (1 - 2\bar{x})}{1 - p} \quad (2.7)
\end{align*}

The practical limits for variation in prismatic coefficient, \(\delta\phi_f\) and \(\delta\phi_a\), to which the fullness of a given form can be varied without resulting in a very steep sectional area curve at the forward or aft ends is given by

\[\delta\phi = \frac{\delta p (1 - \phi) \pm \frac{1}{2} A \left(1 - \frac{\delta p}{1 - p}\right)}{1 - p} \quad (2.8)\]

The various constants involved in the above equations refer to either the fore or the aft bodies as required. It is assumed that the reader has a basic knowledge of the coefficients of form of a ship hull. Otherwise, a detailed explanation can be found in the Principles of Naval Architecture, Vol 1 [6].

### 2.2 Effect of Variation in LCB

The effect of change in LCB position is very nominal up to a critical speed-length ratio, but above this critical limit the variation of LCB is very prominent [11].

**Effect on Resistance**

The effect of increase in speed is very prominent on the resistance of a vessel. The optimum position of LCB appears to move aft with increasing speed. Of course this depends on the hull shape.
Other Effects

Changes in position of LCB seem to have less influence on the factors such as wake fraction, thrust-deduction fraction, hull efficiency and quasi-propulsive coefficient. But as this evaluation is done on a specific series of hull model, the effect can be validated as an optimization constraint.

2.3 Panel Method

Boundary Element Method

In the last twenty years, the boundary-element method (BEM) has been established as a powerful numerical technique for dealing with a variety of problems in science and engineering involving elliptic partial differential equations. The strength of the method derives from its ability to solve, with remarkable efficiency and accuracy, problems in domains with complex and possibly evolving geometry where traditional methods can be inefficient, cumbersome, or unreliable.

Various elements (elementary solutions) exist to approximate the disturbance effect of the ship. These more or less complicated mathematical expressions are useful to model displacements(sources) or lift(vortices or dipoles). The basic idea of all the related boundary element methods is to superimpose elements in an unbounded fluid. Since the flow does not cross a streamline just as it does not cross real fluid boundary (hull), any unbounded flow field in which a stream line coincides with the actual flow boundaries in the bounded problem can be interpreted as a solution for bounded flow problem in the limited fluid domain.

Panel Methods for computing the ship wave resistance in potential flow is one form of a boundary element method where the ship hull is discretized into number of quadrilateral and triangular panels with rankine sources distributed at each panel centre.

This method assumes inviscid and non-lifting flows. Body boundary condition and a
linearised free surface boundary condition are applied in the current version of the panel method used. After solving for the source strengths at the panel centres. The pressure distribution is then integrated to get the net forces acting on the body, which is the sum of longitudinal force component, sinkage force and trimming moment of the ship moving in fluid domain. In solving the potential flow, the free surface panels are raised above the actual free surface to avoid singularities.

2.4 Optimization

Nelder Mead simplex, a simple yet efficient optimization algorithm is selected for this problem. The algorithm is very effective for the present problem. For the present case, it is a known fact that the optimum LCB is located near the midships. So, the initial guess for the optimization process is made at the midship.

2.4.1 Algorithm

The Nelder-Mead algorithm or simplex search algorithm, originally published in 1965 [9], is one of the best known algorithms for multidimensional unconstrained optimization. The basic algorithm is quite simple to understand and very easy to use. The method does not require any derivative information, which makes it suitable for problems with non-smooth functions. It is widely used to solve parameter estimation and similar statistical problems, where the function values are uncertain or subject to noise. [15].

Even though the method is quite simple, it is implemented in many different ways. Apart from some minor computational details in the basic algorithm, the main difference between various implementations lies in the construction of the initial simplex, and in the selection of convergence or termination tests used to end the iteration process. The general algorithm is given below (figure 2.1).
1. Construct the initial working simplex.

2. Repeat the following steps until the termination test is satisfied.

3. Calculate the termination test information.

4. If the termination test is not satisfied then transform the working simplex.

5. Return the best vertex of the current simplex and the associated function value.

In many practical problems a highly accurate solution is not necessary and may be impossible to compute. All that is desired is an improvement in function value, rather than full optimization. Though a true optimum is always better, there are limitations in lieu of the computation time required.

The Nelder-Mead method frequently gives significant improvements in the first few iteration and generally produces satisfactory results. Also, the method typically requires only one or two function evaluations per iteration, except in shrink transformations. This is very important in applications where each function evaluation is very expensive or time-consuming. For such problems, the method is often faster than other methods, especially those that require at least some function evaluations per iteration.

- **Pro:** In many numerical tests, the Nelder-Mead method succeeds in obtaining a good reduction in the function value using a relatively small number of function evaluations. Apart from being simple to understand and use, this is the main reason for its popularity in practice.

- **Con:** The method can take an enormous amount of iterations with negligible improvement in function value, despite being nowhere near a minimum. This usually results in premature termination of iterations. A heuristic approach to deal with such cases is to restart the algorithm several times, with reasonably small number of allowed iterations per each run.
Figure 2.1: Nelder Mead Simplex Flow Chart [3]
Chapter 3

Methodology

Hull shape optimization for a minimum resistance can be achieved using any of the geometric variation processes as discussed in chapter 2. However, our goal is to optimize ship hull with a minimum deviation from the shape of the parent hull. For this reason, the variation of LCB using Lackenby’s method of transformation [5] is considered appropriate.

3.1 Optimization Loop

The first step in the optimization loop is to read the hull geometry, where the hull offsets are defined and boundary surfaces are discretized. Surface discretization has a direct influence on the accuracy of any computational fluid dynamics solution. The ship hull geometry is represented as a point distribution along the girth at every station on the hull surface. For the purpose of discretization of hull surface into panels, the station spacing is changed and controlled using a shape function. The panels are divided at every station and are equally spaced girthwise. This kind of panel distribution will allow the optimization to work with Lackenby transformation without the necessity for panel generation during each and every iteration. Based on the type of the hull, subdivision of panels into zones is applied.

The second step is to find the resistance of the ship hull. This will serve as objective function for the optimization process. A panel code developed by Dr. Lothar Birk [4] is used
for calculation of wavemaking resistance of the ship hull. The panel code is a FORTRAN 90 program which accepts a panel input file along with other control parameters.

Finally, the optimization process is carried out using a PYTHON module which uses the Nelder - Mead simplex algorithm (section 2.4) for control. The algorithm find the optimized location of LCB for a particular speed.

3.2 Objective Function

The process of optimization iterates through the objective function (figure 3.1). The functional value of wave making resistance is calculated by

- Reading hull geometry.
- Creating hull patches.
- Hull and free surface panel generation.
- Generating panel input and control files.
- Computing wave making resistance.

3.3 Geometry Acquisition

The hull surface has to be represented with a panel distribution of varying panel sizes. For any computational fluid dynamics code to perform an accurate analysis, the panels have to be distributed uniformly and uniquely concentrated at locations where the flow is more complex. For a typical ship hull the flow near the bow and stern have large changes in flow velocities. Thus a concentrated panel distribution is applied to the ends of the hull.

The hull is typically divided into four primary panel zones. The zones are divided according to the boundary variables specified in the input. All the four zones has a typical
Figure 3.1: Objective function flow chart
panel generation scheme, which can be generated using a linear interpolation or a Lagrangian interpolation.

Panel zones maintain a consistent distribution by using a predefined global panel distribution shape function. The zone division process can be applied to any typical hull geometry, which are symmetric. Ships with a bulbous bow, transom stern, cruiser stern or centreline propeller bossing can be handled effectively by the panel zone division.

3.3.1 Geometry Input

The hull surface is defined by a standard GHS geometry file which contains all the information about the geometry of the vessel, represented in detail appropriate for hydrostatic and stability calculations (figure 3.2). It describes the volumes of the hull and various compartments. Each volume to be modelled consists of a series of transverse sections, arranged from bow to stern. A geometry file can be generated either by manually typing offsets or by using any other modelling software, Rhino3D is being used for this work. The geometry file should have a centerline symmetric marker distribution without repeated values. Centerline symmetric values can be defined on either port or starboard side.

Within the geometry file one or more components are defined together to form the complete watertight hull surface. This surface is specified in the input to make the process of hull generation more easier. Markers (offset points) in a geometry file are distributed along every station and they are stored into a standard offset array.

The number of markers may or may not be the same for every station. So, a girth wise subdivision is implemented to make them uniform. These offsets are stored in the offset variable, of dimensions \(\text{no. of points for a station} \times \text{no. of stations} \times 2\) (for \(y\) and \(z\))”. The \(y\) offsets are represented in Array \([\cdot; \cdot; 0]\) and the corresponding \(z\) offsets in Array \([\cdot; \cdot; 1]\).

The offsets are passed through a sanity check to verify that they are increasing in height. A warning shows up when such a problem is encountered. This helps is verifying the geometry
file for consistency.

3.3.2 Panel Zones

Every hull is divided into four basic panel zones. This facilitates better way to generate panels and representation. Panel zones are defined on the basis of boundary lines and hull shape. Four variations in the zone distribution have been implemented for different types of conventional vessels (figure 3.3):

- Type 1:
  Center line propeller bowing - present.
  Bulbous bow - present.

- Type 2:
  Center line propeller bowing - absent.
  Bulbous bow - present.

- Type 3:

• Type 1:
  Center line propeller bowing - present.
  Bulbous bow - present.

• Type 2:
  Center line propeller bowing - absent.
  Bulbous bow - present.

• Type 3:
Center line propeller bossing - present.
Bulbous bow - absent.

- Type 4:
  Center line propeller bossing - absent.
  Bulbous bow - absent.

For each of the above cases the first zone will be the lower stern surface which includes the bossing if present. The second zone will be the upper stern surface. Third zone will be largest surface zone, the middle body surface. Last zone is defined for the bulbous bow surface.

3.3.3 Panel Generation

Though panels can be generated from the predefined stations, a controlled variation of panel distribution is essential for computational accuracy. A shape function is used to calculate and control the new distribution of panel stations. Panel stations are generated by a simple local interpolation of points in the three dimensional domain. Two approaches, linear interpolation and Lagrangian interpolation, are considered for interpolating along the local domain.

Linear Interpolation

For every new station, two nearest stations are selected and a new $y$ and $z$ ordinates are interpolated for the longitudinal ($x$ ordinate) position of the station. As the stations are equally divided along the girth, the number of interpolated points will be the same in each station. Thus a vector interpolation is used to generate the same number of points at a new station location. The interpolation is operated independently over each girth point of same index along two selected stations. The two stations are adjacent to each other and are nearest to the required new station location.
Figure 3.3: Different types of conventional vessels
Lagrangian Interpolation

This is a simple quadratic interpolation where three nearest stations are selected and an approach similar to linear interpolation is used to find the Lagrangian interpolation polynomials. For every new station location and for every girth interval, a new point is determined from the Lagrangian interpolation polynomial.

The old panel file (figure 3.2) is interpolated using any of the interpolation methods. The new panel points are more structured and cleaned up as shown in fig 3.4. The number of points in the new stations depend on the required aspect ratio and the input file specifications.

Figure 3.4: Panel points
3.4 Panel Code

The Panel method is used for finding a solution to the potential flow around a ship hull (chapter 2.3). The panel code developed by Dr. Lothar Birk is designed to run using a panel file and a control file. The input panel file (* .pan) has a basic structure which first defines length, symmetry condition, number of hull patches, number of free surface patches, total number of hull points & panels and total number of free surface points & panels. The panel zone location and orientation is also specified. All the points are specified and the detailed orientation of every panel is listed.

The panel file is the most significant input that is defined after considering geometric approximations and appropriate free board panel raise. The rise in free board is specified by an $\alpha$ factor, which serves as an intermediate input for panel file generation (figure 3.5).

3.5 Optimization Module

A typical optimization requires an optimization method and a function, which has to be minimized. In this case the function is evaluated on the basis of resistance from panel code. The function is designed to take LCB position as a free variable. The optimizer will thus find the optimum LCB location at which the resistance is a minimum (figure 3.5).

3.5.1 Function

The function value is the coefficient of wave making resistance at a particular speed. This is evaluated using panel code [4] which writes the output to an output file. This value is used by the Nelder Mead simplex algorithm for its evaluations. The value of wave resistance will become higher as we move away from the optimum point and there is only one optimum location of LCB. The wave field created by the ship is sensitive to the panelization. The hull creates almost realistic wave field (figure 3.6), with a higher elevation at the transom.
Figure 3.5: Optimizer Flow Chart
3.5.2 Free Variable

Longitudinal Center of Buoyancy is one of the critical parameters which influence the wave resistance of a ship moving in fluid domain. A general observation is that, at higher speeds the LCB shifts towards aft and the contrary for slow speeds. This a very sensitive variable which of course depends on the geometry and type of ship. So every ship has to be checked for an optimum LCB for the design operation conditions. The functional change in wave resistance for change in LCB is facilitated by changing hull form for required change in LCB by using Lackenby transformation [5].

3.5.3 Shape Transformation

In the present work, only LCB is considered as a free variable. When the LCB is shifted to one side, the sectional area curve is also shifted to the same side. This will impose a
change in new station position, which is governed by Lackenby transformation method, thus changing the panel file. The panel file is designed to take station data and station spacing as input. As the station location changes, the only change made is the station location input given to the panel file generation module. The rest of the process stays the same (figure 3.5).
Chapter 4

Results

The optimization of LCB position, for minimum wave resistance, using a panel method (section 3.3) was developed as a generic process. For the purpose of validation and discussion a standard hull form [14] is considered for analysis. The results thus obtained are compared with published technical data.

The optimization process has been carried out for a container ship hull of 53330 tons displacement, advancing in calm water at a speed of 24 knots (Fn = 0.26) in fixed condition (i.e., sinkage and trim not allowed). The optimization is applied only to the submerged hull. Resistance due to wind and appendages are not taken into consideration. More precisely, in the presented results the modification refers to just the submerged hull. Furthermore, in the hull transformations, only the x-coordinate of the hull is allowed to vary, while the transverse sections are kept fixed.
4.1 Input Data

As discussed earlier in 3.3, the process can be categorised into three sections. Each of them requires a specific input and they will generate output which will be passed on to the next. The geometry acquisition reads the hull geometry file and it generates a panel file. The panel code uses a panel file and a control file to generate the resistance. The resistance of the ship hull respective to a particular LCB position serves as an objective function for the optimization process.

4.1.1 Geometry

KRISO container ship (KCS) [14] is considered for analysis in this project. The KCS was conceived to provide data for validation of flow physics and CFD for a modern container ship with bulb bow and stern. Even though there is no existing ship exactly of same dimensions, but a similar ship is operated for Maersk Lines, the SUSAN MAERSK (figure 4.1) which is one of the largest container ship’s in the world.

Korea Research Institute for Ships and Ocean Engineering performed towing-tank experiments to obtain resistance and wave field data for this ship. The data is available in the KCS website [14].

Main Particulars

- Length between Perpendiculars, $L_{pp} = 230.0$ m
- Breadth, $B = 32.2$ m
- Depth, $D = 19$ m
- Draft, $T = 10.8$ m
- Volume of displacement, $V = 52030.0$ m$^3$
• Wetted surface area, $\Omega = 9424.0 \ m^2$

• Block Coefficient, $C_b = 0.6505$

• Mid ship section area coefficient, $C_m = 0.9849$

• Longitudinal center of buoyancy, LCB = -1.48 % of Lpp from midships

Offsets Data: The offset file of KRISO container ship is provided as an input, either a GHS geometry file format or as a xyz offset data. The data provided has a distribution of one hundred points at ever station (figure 4.2). These stations are interpolated using linear interpolation along the length of the vessel. A numerical integration method is used for the calculation of form parameters of the vessel.

4.1.2 Panel Code

The panel code reads the geometry from a panel file (*.pan) and control parameters from a control file (*.in). A panel file is a detailed representation of all the panel points and their relative location. Whereas, the control file specifies the data which specifies the details of
the input and the output files, Froude number, free surface condition, flow condition etc. The code solves primarily for the pressure distribution. Later on wave making resistance, stream lines and free surface deformation are evaluated. Post processing of these output files is carried out using ParaView (figures 4.3 & 4.4).

4.1.3 Optimization

As a basic optimization input a function to be optimized and an initial guess are defined. The function for optimization is the wave making resistance of the hull at design speed. The
panel file which represents the hull is already generated from geometry acquisition module. The panel stations are transformed using a lackenby transformation to achieve required LCB position for the hull. The LCB position is the variable for the optimization problem and at the end of optimization, an optimum location of LCB is determined.

Input for optimization module is:

- Speed, \( V = 24 \) knots
- Froude number, \( F_n = 0.26 \)
- Parameter for raised panel height, \( \alpha = 0.8 \)
- Initial guess of LCB shift of \(-0.05\%\) (of half length of \( L_{pp} \)) from midships. This position is definitely at a close proximity from the optimum location of LCB.
4.2 Output

Optimization algorithm searches for an optimum LCB position for a particular speed of ship.
The coefficient of resistance starts at an initial guess value and gradually converges to a minimum (figure 4.5).

4.2.1 Optimization Output

- Number of Iterations = 9
- Total number of function evaluations = 19
- Minimum Coefficient of Wave Making Resistance, $C_w = 0.00256509$
- Optimized LCB location as a percentage of $L_{pp}$ from midship = -1.65

The optimum LCB is 3.795 m aft of midships
Figure 4.5: Optimization convergence at speed of 24 knots
Chapter 5

Discussion

1. **LCB position**: The location of optimized LCB is observed to be located aft of midships. This is as expected in view of hydrodynamics of a ship hull. The position of LCB as provided in a Flow Vision document [10] is -1.48 % of Lpp from midship. The observed value, -1.653 % of Lpp, is almost close to the published results and the deviation of 0.17 % with respect to Lpp. This might be for the reasons that the hull is approximated using linear panels.

2. **Wave making resistance**: The coefficient of wave making resistance, $C_w = 0.002565$, is more than three times of what it actually should be, value of $C_w = 0.000731$ as published [14].

   There are a lot of assumptions involved in calculating the resistance such as linearized free surface, geometry approximation using linear panels and the panel method itself. But, they will not effect the determination of optimized LCB position. The optimization algorithm only considers relative nature of resistance with change in LCB position.

3. **Wave pattern**: The wave pattern formed by the ship hull is in agreement with the standard kelvin wave pattern with and half angle of 19.47 deg. The measured angle is 19.45 deg (figure 5.1)
4. **Transom wave profile:** wave height at transom (figure 5.2) is higher than the measured wave profile data [14]. This is a general trend in panel methods for a ship hull.

5. **Froude number:** The position of optimum LCB is observed to show a decreasing
trend (shifting towards aft) with increasing Froude number (figure 5.3). Further the LCB is expected to shift towards aft.

![Figure 5.3: Froude Number vs LCB](image)

Figure 5.3: Froude Number vs LCB
Chapter 6

Conclusions

A generic method for optimization of ship hulls using panel method is presented. This method uses a simple interpolation scheme to generate panels for any conventional ship hull. The use of stations as a grid to develop panels eliminates the necessity to regenerate the panels for every iteration. This resulted in a significant improvement in computational speed. Lackenby transformation is used by the optimization algorithm to incorporate variation in hull geometry for a required LCB shift. A simple, yet efficient Nelder - Mead simplex method of optimization is used for this problem. In conclusion this approach has successfully determined the optimum location of LCB for a standard container ship hull.

The obvious advantages of this method include the ability to represent any conventional ship hull using a simple interpolation scheme for panel generation, an approximation which is reliable. Also, the use of lackenby method of transformation enables a control over preserving the volume and over all dimensions, while making a change in LCB position. The optimization algorithm selected is also very efficient in solving this kind of a problem.

The results from this work concur with published data and theory. The present approach focuses on locating an optimum LCB position for a ship hull and also observing the resistance characteristics of a ship hull at different speeds. The key point is achieving a best design lies in matching a ship hull with its operational conditions. The approach presented will enable a designer to identify the best possible design alternative for a selected condition.
Further, the panel method can be extended to handle transom immersion, appendages, trim and heel. The next milestone would be a panel code that includes non-linear free surface conditions. The range of free variable of optimization has to be extended to bulbous bow shape and also the over all dimensions. To add up, a stability approach would enhance the feasibility of the ship hull design.
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# Mar 03, 2010
# kkarri, Hull shape optimization using lackenby transformation
# and Nelder−mead simplex algorithm

# importing required packages

import numpy as np
from scipy.integrate import trapz, simps
from scipy.io import savemat
from subprocess import call

# . . . . . . . . . . . Pre defined functions . . . . . . . . . . . . . . . . .

def readoffsets(filename, T):
    """
    Function to read offset file
    Input: filename of offsets file
    T is the draft
    Output: xlong = station spacing along x axis from AP
    offsets = offsets stores half breadth as [station number, half
    breadth, 0]
    offsets stores height as [station number, height above
    baseline, 1]
    Across = Sectional area at each station.
    """
f = open(filename,"r")
lines=[]
data=[]
original_lines = f.readlines()
for line in original_lines:
    line = line.strip()
    if line[0]!="#":
        lines.append(line)
f.close()

# create storage space for data of dimension (number of stations, no of points, 2)
offsets = np.zeros((57,100,2),float)

# offset lines read for data
# xlong is longitudinal distance of section from AP,
xlong = []
yst = []
zst = []
for i in np.linspace(0,2296,57):  # for reading data in lines
    xlong.append(float(lines[int(i)].split()[0]))
b = []
h = []
for j in np.linspace(1,20,20):
    b.append(lines[int(i)+int(j)].split())
    h.append(lines[20+int(i)+int(j)].split())

offsets[int(i/41),:,0] = np.reshape(b,np.size(b))  # b assigned to offsets
offsets[\text{int}(i/41), :, 1] = \text{np.reshape}(h, \text{np.size}(h)) \quad \# h assigned to offsets
ysts.append(offsets[\text{int}(i/41), :, 0])
zst.append(offsets[\text{int}(i/41), :, 1])
xlong = \text{np.asarray}(xlong)

\# Across stores Sectional Area of each station
Across = []
Girth = []
for i in \text{range}(0, 57): \quad \# runs through all stations
  A=0
  for j in \text{range}(0, 99): \quad \# runs through all points
    \# The cross-sectional area is calculated up to draft
    if offsets[i, j+1, 1] < T :
      \# for $h < T$, sec area is calculated by adding up area of
      \# Trapeziums
      A = A + 2\ast((\text{offsets}[i, j+1, 1] - \text{offsets}[i, j, 1]) \ast 0.5\ast
      \ast(\text{offsets}[i, j, 0]+\text{offsets}[i, j+1, 0]))
    else :
      \# $b_T = b_{previous} +(\text{delta}_B / \text{delta}_h) \ast (T-b)$
      b_T = offsets[i, j, 0] +((\text{offsets}[i, j+1, 0]-\text{offsets}[i, j, 0])\ast(T-\text{offsets}[i, j, 1])/(\text{offsets}[i, j+1, 1] \\
        - \text{offsets}[i, j, 1]))
      A = A + 2\ast((T - \text{offsets}[i, j, 1]) \ast 0.5\ast
      \ast(\text{offsets}[i, j, 0]+b_T))
    break
Across.append(A)

\# generating offset array
\#offsets stores half breadth as [station number, half breadth, 0]
\#offsets stores height as [station number, height above baseline, 1]
```python
y = offsets[i,:,0]
z = offsets[i,:,1]

# v = number of points along girthwise
v = 99
dist = ((np.diff(y))**2 + (np.diff(z))**2)**0.5
girth = np.zeros(len(dist)+1)
delta = np.zeros(v+1)

for k in range(len(dist)):
girth[k+1] = girth[k] + dist[k]

zpan = []
ypan = []

for k in range(int(v)):
delta[k] = sum(dist)*k/v

for j in range(1,len(girth)):
    if (girth[j-1] <= delta[k])&(girth[j] > delta[k]):
        ypan.append(y[j-1] + ((y[j]-y[j-1])*(delta[k]-girth[j-1]))
        (girth[j]-girth[j-1]))
        zpan.append(z[j-1] + ((z[j]-z[j-1])*(delta[k]-girth[j-1]))
        (girth[j]-girth[j-1]))

Girth.append(girth[-1])

Girth = np.asarray(Girth)

Across = np.asarray(Across)\n
return xlong, offsets, yst, zst, Across, Girth
```

```python
def patch(xlong, offsets, sta, p, vp, r, vl, vu, sx, sy, sz, tx, ty, tz, bx, by, bz, beta, Lpp, T):
    ""
```
**INPUT:**

*sta*: station number or array. Specifies stations of a patch

*p*: patch number: 1—stern tube; 2—transom; 3—hull body; 4—bulb

*v*: no of panels girthwise ??

*r*: ?

```
x = []
y = []
z = []

if p == 1:
    # patch 1 (stern tube) is closed at aft end
    for i in range(vl+1):
        x.append(sx)
y.append(sy)
z.append(sz)

if p == 2:
    # patch 2 (transom) is closed at aft end
    for i in range(vu+2):
        x.append(tx)
y.append(ty)
z.append(tz)

    # patch closure at the end for free board panel
    z[-1] = (tz + (beta * Lpp))

for i in sta:
    # runs through all stations
    z1, y1, ystart, yend = station(i, offsets, beta, Lpp, T)
ypan, zpan = stadiv(z1, y1, ystart, yend, p, vp, vl, vu, i, sta[0], 8.96)

    if p == 1:
```
for j in range(len(ypan[0])):
    x.append(xlong[i])
    y.append(ypan[0][j])
    z.append(zpan[0][j])
if p == 2:
    if np.size(ystart) == 1:
        for j in range(len(ypan)):
            x.append(xlong[i])
            y.append(ypan[j])
            z.append(zpan[j])
    elif np.size(ystart) == 2:
        for j in range(len(ypan[1])):
            x.append(xlong[i])
            y.append(ypan[1][j])
            z.append(zpan[1][j])
    if (p== 3) | (p ==4):
        for j in range(len(ypan)):
            x.append(xlong[i])
            y.append(ypan[j])
            z.append(zpan[j])
if p == 4:
    # patch 4 (bulbous bow) is closed at fwd end
    for i in range(vp +1):
        x.append(bx)
        y.append(by)
        z.append(bz)
    return np.rot90(np.reshape(x,(-1,r+1)),-1),
    np.rot90(np.reshape(y,(-1,r+1)),-1),
    np.rot90(np.reshape(z,(-1,r+1)),-1)-T

def station(i, offsets, beta,Lpp,T):
"""
INPUT:

i = station number

OUTPUT:

z = actual station water lines
y = actual station offsets

z1 = station water lines upto Load Water Line
y1 = station offsets upto Load Water Line

p = returns the number of discontinuous sections (i.e. for transom p = 2
    as there are two discontinuous section lines

ystart = specifies the start points of sections
yend = specifies the end points of sections

note: Sections are defined as continuous station lines,
    for example: transom section, stern tube section, body sections,
    bulbous bow section.
"""

z = []
y = []

# This loop selects the submerged portion of the hull and freeboard
# i.e. upto water line and free board, stores offsets in y and z

for j in range(0,99):
    # runs through all points
    if offsets[i,j,1] < T:
        z.append(offsets[i,j,1])
        y.append(offsets[i,j,0])
    else:
        b_T = offsets[i,j,0] +((offsets[i,j+1,0]-offsets[i,j,0])\
            *(T-offsets[i,j,1])/(offsets[i,j+1,1] \}
z.append(T)
y.append(b_T)

# for freeboard offsets
fb = beta * Lpp
T_fb = T + fb
j = np.nonzero(offsets[i,:,1] >= T_fb)[0][0] - 1
b_fb = offsets[i,j,0] +((offsets[i,j+1,0] - offsets[i,j,0])
  *(T_fb-offsets[i,j,1])/(offsets[i,j+1,1] 
  - offsets[i,j,1]))
z.append(T_fb)
y.append(b_fb)
break

# y1 ans z1 returns the values of interpolated values upto WL
z1 = []
y1 = []
# this is returned with a value specifying no. of patches
ystart = []
yend = []
for k in range(1,len(z)):
    if (y[k] > 0.) & (y[k-1] == 0.):
        ystart.append(k-1)
yend.append(len(z)-1)
y1.append(y[k-1])
z1.append(z[k-1])
y1.append(y[k])
z1.append(z[k])
elif (y[k] > 0.) & (y[k-1] > 0.):
    y1.append(y[k])
```python
z1.append(z[k])

elif (y[k] == 0.) & (y[k-1] > 0.):
yend[len(yend)-1] = k
y1.append(y[k])
z1.append(z[k])

return z1, y1, ystart, yend

def stadiv(z1, y1, ystart, yend, p, v, vl, vu, i, bs, tb):
    
    """This function divides a section into equal patches

    INPUT:
    z1 = water line spacing
    y1 = half breadth
    ystart = specifies the start points of sections
    yend = specifies the end points of
    p = no. of patches
    v = number of patches in vertical direction
    i = station number
    bs = station number at bulb closing, generally sta[0]
    tb = trimming draft at bulb, points above tb are neglected in bulb patch

    OUTPUT:
    ypan and zpan are the offsets for the panel points
    """

    # division for stations with continuous sections
    if (np.size(ystart) == 1) | (p == 3):
        ypan, zpan = girthdiv(v, y1, z1, 1)

    # division for bulb sections
    if p == 4:
        if (i == bs) & (p == 4):  # for bulb join station
```

---

45
# this line makes the bulb an approximate cylinder
up = np.nonzero(np.array(z1)>tb)[0][0]
ypan, zpan = girthdiv(v,y1[:up],z1[:up],0)
else:
ypan, zpan = girthdiv(v,y1,z1,0)

# division when there are discontinuous sections
elif (np.size(ystart) == 2) & (p != 3)&(p!=4):
y1l = y1[0:yend[0]−ystart[0]+1]
y1u = y1[yend[0]−ystart[0]+1:len(y1)]
z1l = z1[0:yend[0]−ystart[0]+1]
z1u = z1[yend[0]−ystart[0]+1:len(z1)]

# for lower patch
ypanl, zpanl = girthdiv(vl,y1l,z1l,0)
# for upper patch
ypanu, zpanu = girthdiv(vu,y1u,z1u,1)

ypan = [ypanl,ypanu]
zpan = [zpanl,zpanu]
return ypan, zpan

def girthdiv(v,y2,z2,wl):
    
    This function divides any given section patch into number of equal panels. The calculation of patch length is based on the length along girth

    INPUT :
v = number of patches in vertical direction
y2 = half breadth
z2 = water line spacing
wl = 1 if patch includes a water line, 0 if it don’t
OUTPUT:

ypan and zpan are the offsets for the divided section patches

""

if wl == 0:
y = y2
z = z2
else:
y = y2[:−1]
z = z2[:−1]
dist = ((np.diff(y))**2 + (np.diff(z))**2)**0.5
girth = np.zeros(len(dist)+1)
delta = np.zeros(v+1)

for i in range(len(dist)):
girth[i+1] = girth[i] + dist[i]
zpan = []
ypan = []

for i in range(int(v)):
delta[i] = sum(dist)*i/v

for j in range(1,len(girth)):
    if (girth[j-1] <= delta[i])&(girth[j] > delta[i]):
        ypan.append(y[j−1] + ((y[j]−y[j−1])*(delta[i]−girth[j−1])\(girth[j]−girth[j−1])))))
zpan.append(z[j−1] + ((z[j]−z[j−1])*(delta[i]−girth[j−1])\(girth[j]−girth[j−1])-)

zpan.append(z[−1])
ypan.append(y[−1])

if wl==1:
zpan.append(z2[−1])
ypan.append(y2[−1])

return ypan, zpan
```python
def stainterp(xlong, zone, pandist, npan, x, y, z):
    # number of points for new stations
    nlen = len(x)
    n_stast = sta_gen(zone, pandist, npan)

    nx = np.zeros([nlen, len(n_stast)], float)
    ny = np.zeros([nlen, len(n_stast)], float)
    nz = np.zeros([nlen, len(n_stast)], float)

    descending = 0
    if np.any(np.diff(x[0]) < 0):
        descending = 1
        x = x[:, ::-1]
        y = y[:, ::-1]
        z = z[:, ::-1]

    for i in range(len(n_stast)):
        if n_stast[i] > x[0][-1]:
            xfloor = len(x) - 1
        else:
            xfloor = np.searchsorted(x[0], n_stast[i])

        xl = x[:, xfloor]
        xr = x[:, xfloor - 1]
        yl = y[:, xfloor]
        yr = y[:, xfloor - 1]
        zl = z[:, xfloor]
```

```python
357  zr = z[:, xfloor -1]

359  for j in range(len(x)):
    delta = ((xr[j]-xl[j])**2 + (yr[j]-yl[j])**2 + 
              (zr[j]-zl[j])**2)**0.5
    t = (n_sta[i]-xl[j])*(delta/(xr[j]-xl[j]))
    nx[j,i] = n_sta[i]
    ny[j,i] = yl[j]+ (t*((yr[j]-yl[j])/delta))
    nz[j,i] = zl[j]+ (t*((zr[j]-zl[j])/delta))

367  if descending == 1:
    nx = nx[:,::-1]
    ny = ny[:,::-1]
    nz = nz[:,::-1]

371  return nx, ny, nz

373  def sta_gen(zone, pandist,npan):

375      

377      Input:
378      zone = [aft ext, fwd ext, xstart, xend]
379          aft and fwd ext are the extreme points on the hull
380          xstart is where the first station starts, xend it where it ends
381      pandist = Panel distribution array = [[-1.0, -.9, -0.25, 0., 0.25, 0.9, 1.0],
382          [0.0, 0.25, 1.0, 1.0, 1.0, 0.25, 0.0]]
383
385      First row - longitudinal axis (normalized
386          Second row represents the variation of panel length form aft to
387            fwd.
388
389      npan = number of panels points

390  OUTPUT:
```
n_sta = normalized new stations in the specified zone

x = np.linspace(min(pandist[0]),max(pandist[0]),100)
y = np.interp(x, pandist[0], pandist[1])
A = []
for i in range(len(x)):
    A.append(trapz(y[0:i+1],x[0:i+1]))
A = np.array(A)

zx = np.interp(np.linspace(zone[2], zone[3], npan),
              np.linspace(zone[0], zone[1], 100), x)
n_sta = np.interp(zx, x, A)

# Normalized
n_sta = n_sta / (n_sta[-1] - n_sta[0])
n_sta = n_sta - min(n_sta)

return n_sta

def visual(x, y, z, p, disp):

    # save final patch offsets to *.arr
    savemat('x_' + str(p) + '.mat', mdict={'arr':x})
    savemat('y_' + str(p) + '.mat', mdict={'arr':y})
    savemat('z_' + str(p) + '.mat', mdict={'arr':z})

    if disp == 1:
        # To view the panels geometry with MATLAB
        fig = plt.figure()
        ax = Axes3D(fig, aspect = 'auto')
        # importing plotting function if required
from matplotlib import cm
from mpl_toolkits.mplot3d import Axes3D
import matplotlib.pyplot as plt

# creating surface plot
ax.plot_surface(x, y, z, rstride = 1, cstride = 1, cmap = cm.jet)
# star board side of hull
ax.plot_surface(x, -y, z, rstride = 1, cstride = 1, cmap = cm.jet)
ax.set_xlabel('X')
ax.set_ylabel('Y')
ax.set_zlabel('Z')

def patchfs(xwl, ywl, fs, vf, T, Lpp, Lwl, delta_s, beta, w_beta):
    ""
    initial free surface points generation
    ""
    INPUT:
    xwl: x coordinates of waterline
    ywl: y coordinates of water line
    fs: Number of Free surface panels for one ship length
    vf: transverse number of panel
    Lpp: Length between Perpendiculars
    delta_s: Factor to determine initial panel offset from Hull water line
             (~ 0.015)
    w_beta: Rate of increase in panel width away from hull. (~ 1.1)
    ""

    #Lwl local
    xfs0 = np.linspace(xwl[0] + (0.5*Lwl), xwl[-1] - (1.5*Lwl), (3*fs) + 1)
    xfs = np.tile(xfs0, (vf+1, 1))
    # number of panels on WL, length wise
    s_fs = np.shape(xfs)[1] - 1
    # Interpolate halfbreadths for patch points of free surface
yfs_0 = np.interp(xfs_0[(0.5*fspan):-(1.5*fspan)+1], [:::-1], 
    xwl[:::-1], ywl[:::-1]) [:::-1]

# attaching panels fwd
yfs_0 = np.append(np.zeros(0.5*fspan), yfs_0)

# attaching panels aft
yfs_0 = np.append(yfs_0, np.zeros((1.5*fspan)+1))

yfs = []
delta = (np.vander([w_beta], v_fs+1)*Lpp*delta_s).squeeze()

for i in range(len(yfs_0)):
    scale = (sum(delta) - yfs_0[i]) / sum(delta)
    delta1 = scale * delta[:::-1]
    yfs.append(yfs_0[i])
    for j in range(1, v_fs):
        yfs.append(delta1[j]+yfs[-1])
        yfs.append(delta_s*w_beta*Lpp*(1 - w_beta**(v_fs))/(1 - w_beta))

yfs = np.array(yfs).reshape(s_fs+1, v_fs+1).T
zfs = np.zeros((v_fs+1, s_fs+1))
fb = beta * Lpp
zfs[...] = T+ fb

return xfs, yfs, zfs-T

def resistance(x0):
    ""
    This function calculates the resistance for the modified hull form
    by dLCB
    ""
    desc = 0
    if np.any(np.diff(nx3[0]) < 0):
desc = 1

xparent = nx3[:, ::-1][0, :]

sacparent = np.interp(xparent, xlong, Across)
# distance of first station from A.P.

min_xp = min(xparent)
# modifying xparent to have first station at x = 0
xparent = xparent - min_xp

# Part 2: Modifying Hull form
xderived, sacparent, CPa, Cpf, pf, CP, LCB = lackenby(xparent, sacparent, dpa=0, dpf=0, dCP=0, dLCB=x0)
# modifying xderived to get back to normal state i.e. first station at
# x = min_xp
if desc == 1:
    xderived = xderived[:, ::-1] + min_xp
else:
    xderived = xderived + min_xp

# Part 3: Calculate resistance using Dr. Birk’s panel code
R = panelmethod(xderived, filename, origin, Lpp, Lwl, nx1, nx2, nx2t, nx3, nx4, nx5,
ny1, ny2, ny2t, ny3, ny4, ny5, nz1, nz2, nz3, nz4, nz5, fspan, v, fs, T, delta_s,
beta, w_beta)

# Part 4: Constraint application
## evaluate constraints for penalty function

c = []  # empty list for constraint values
```python
# constraints
c.append(lcbrange(LCB, xparent[-1]))

# convert the list to a numpy array (for faster math)
c = np.asarray(c)

# Define and compute exterior penalty function
r = 1.e10

"""
Multiplication by a huge number
"""
P = np.sum(c*c)

print "Longitudinal center of Buoyancy, LCB = %12.12f" % LCB
print "Resistance, R = %12.12f" % R
print "Penalty function, r*P = %f" % (r*P)
print "\n"
fp = open("optimization"+str(Vs)+'_'+str(alpha)+".dat", 'a')
fp.write(' %12.12f %12.12f\n' % (LCB, R))
fp.close()
return R + r*P

def lackenby(xparent, sacparent, dpa, dpf, dCP, dLCB):

# parallel mid boy data
p = 0.0  # total length of parallel midbody / half length
pa = 0.00  # par. midbody aft of midship / half length
pf = p - pa  # par. midbody forward of midship / half length

# extract parent hull data
L, midship, AM, V, CP, LCB, CPa, CPf, LCBa, LCBf, ka, kf = \
```
gethulldata(xparent, sacparent)

dx, xderived = getstationshifts(xparent, imidship, dpa, dpf, dCP, dLCB, L,
    p, pa, pf, CP, CPa, CPf, LCB, LCBa, LCBf, ka, kf)

L, imidship, AM, V, CP, LCB, CPa, CPf, LCBa, LCBf, ka, kf = \
    gethulldata(xderived, sacparent)

return xderived, sacparent, CPa, CPf, pf, CP, LCB

def gethulldata(xsta, sac):
    # length (x pointing positive forward)
    L = xsta[-1]

    # maximum sectional area
    AM = max(sac)

    # displacement
    # integration by Simpson’s rule
    V = simps(sac, x=xsta, even='last')

    # Prismatic coefficient
    CP = V / (L*AM)

    # Compute longitudinal center of buoyancy (LCB)
    LCB = simps(sac*xsta, x=xsta, even='last') / V

    # Find index of midship or maximum section position
    for i in range(len(xsta)):
        if (sac == max(sac))[i]:
            imidship = i
    break
# xposition of midship
xm = xsta[imidship]

# Compute prismatic coefficients, LCBs and radius of gyration

# for fore body
Vf = simps(sac[imidship:], x=xsta[imidship:], even='last')
CPf = Vf / ((L-xm)*AM)
LCBf = simps(sac[imidship:]*(xsta[imidship:]-xm),
            x=(xsta[imidship:]-xm), even='last') / Vf
kf = np.sqrt(simps(sac[imidship:]*((xsta[imidship:]-xm)**2),
                  x=(xsta[imidship:]-xm), even='last') / Vf)

# and aft body
Va = simps(sac[:imidship+1], x=xsta[:imidship+1], even='last')
CPa = Va / ((xm)*AM)
LCBa = simps(sac[:imidship+1]*(xm-xsta[:imidship+1]),
             x=-(xm-xsta[:imidship+1]), even='last') / Va
ka = np.sqrt(simps(sac[:imidship+1]*((xm-xsta[:imidship+1])**2),
                   x=-(xm-xsta[:imidship+1]), even='last') / Va)

# refer LCB to midship and make dimensionless with half length
LCB = (LCB-xm)/xm

# make data dimensionless where still necessary
LCBa = LCBa/xm
ka = ka/xm
LCBf = LCBf/(L-xm)
kf = kf/(L-xm)

return L, imidship, AM, V, CP, LCB, CPa, CPf, LCBa, LCBf, ka, kf
def getstationshifts(xparent, imidship, dpa, dpf, dCP, dLCB, \
        L, p, pa, pf, CP, CPa, CPf, LCB, LCBa, LCBf, ka, kf):
    
    """ Computes station shifts using Lackenby’s method """
    
    dx = e(1-x)(x+d)
    """

    # Step 1: Compute constants A, B, C for fore and aft body
    Aa = A( pa, CPa, LCBa )
    Af = A( pf, CPf, LCBf )
    Ba = B1( pa, Aa, CPa, LCBa, ka )
    Bf = B1( pf, Af, CPf, LCBf, kf )
    Ca = C( pa, Ba, CPa, LCBa )
    Cf = C( pf, Bf, CPf, LCBf )
    
    # Step 2: Compute necessary changes in CPa and CPf)
    # Lackenby’s equations
    dCPf = ( 2.*dCP*(LCB+Ba) + dLCB*(CP+dCP) ) + dpf*Cf - dpa*Ca ) / (Ba+Bf)
    dCPa = ( 2.*dCP*(Bf-LCB) - dLCB*(CP+dCP) ) - dpf*Cf + dpa*Ca ) / (Ba+Bf)

    # Step 3: Compute constants for shift function
    ea = e( dpa, dCPa, pa, Aa, CPa)
    ef = e( dpf, dCPf, pf, Af, CPf)
    da = d( dpa, pa, ea)
    df = d( dpf, pf, ef)

    # Step 4: compute shifts and new station positions
    xderived = np.zeros((len(xparent)), float)
    dx = np.zeros((len(xparent)), float)
# aft ship

\[
x_m = x_{parent}[imidship] \\
\text{for } i \text{ in range(imidship)}:\n\quad x = (x_m - x_{parent}[i]) / x_m \\
\quad dx[i] = (-ea * (1.-x) * (x + da)) * x_m \\
\]

# fore ship

\text{for } i \text{ in range(imidship+1,len(xparent))}:
\[
\quad x = (x_{parent}[i]-x_m) / (L-xm) \\
\quad dx[i] = (ef * (1.-x) * (x + df)) * (L-xm) \\
\]

\[x_{derived} = x_{parent} + dx\]
\[\text{return } dx, x_{derived}\]

\[\text{def } A(p, CP, LCB):\]
\[\quad \text{return } CP * (1.-2.*LCB) - p * (1.-CP)\]

\[\text{def } B1(p, A, CP, LCB, k):\]
\[\quad \text{return } CP/A * (2.*LCB - 3.*k**2 - p * (1.-2.*LCB))\]

\[\text{def } C(p, B, CP, LCB):\]
\[\quad \text{return } (B * (1.-CP) - CP * (1.-2.*LCB)) / (1.-p)\]

\[\text{def } e( dp, dCP, p, A, CP):\]
\[\quad \text{return } (dCP - dp/(1.-p) * (1.-CP)) / A\]

\[\text{def } d( dp, p, e):\]
\[\quad \text{return } dp/(e * (1.-p)) - p\]
def panelmethod(xderived, filename, origin, Lpp, Lwl, tx1, tx2, tx2t, tx3, tx4, tx5, ty1, ty2, ty2t, 
        ty3, ty4, ty5, tz1, tz2, tz2t, tz3, tz4, tz5, fspan, v_fs, T, delta_s, beta, 
        w_beta):

    tx3 = np.tile(xderived, (np.shape(tx3)[0], 1))

    # Waterline panel points
    txwl = np.append(tx3[-1], tx2[-1])
    txwl = np.append(txwl, tx2t[-1][1:])
    tywl = np.append(ty3[-1], ty2[-1])
    tywl = np.append(tywl, ty2t[-1][1:])

    tx5, ty5, tz5 = patchfs(txwl, tywl, fspan, v_fs, T, Lpp, Lwl, delta_s, beta, w_beta)

    # "panfile" creates the *.pan file
    panfile(filename, origin, Lwl, tx1, tx2, tx2t, tx3, tx4, tx5, ty1, ty2, ty2t, ty3, ty4, 
        ty5, 
        tz1, tz2, tz2t, tz3, tz4, tz5, fspan)

    call(['"nlhsfs"","nlhsfsctrl.in","run.log"'])

    fp = open('run.log', 'r')
    lines = fp.readlines()
    for line in lines:
        line = line.split()
        if line[0]!="#":
            Cw = float(line[2])
    fp.close()

    return Cw
def panfile(filename, origin, Lwl, px1, px2, px2t, px3, px4, px5, py1, py2, py2t, py3, py4, py5, \
    pz1, pz2, pz2t, pz3, pz4, pz5, fspan):
    reflength = Lwl
    grav = 9.81
    symx = 0
    symy = 1
    nhullpatches = 5
    nfspatches = 1
    nhullpoints = np.size(px1) + np.size(px2) + np.size(px2t) + np.size(px3) + np.size(px4)
    nfspoints = np.size(px5)
    nhullpanels = (np.shape(px1)[0]-1)*(np.shape(px1)[1]-1) + \
        (np.shape(px2)[0]-1)*(np.shape(px2)[1]-1) + \
        (np.shape(px2t)[0]-1)*(np.shape(px2t)[1]-1) + \
        (np.shape(px3)[0]-1)*(np.shape(px3)[1]-1) + \
        (np.shape(px4)[0]-1)*(np.shape(px4)[1]-1)
    nfspanels = (np.shape(px5)[0]-1)*(np.shape(px5)[1]-1)
    fp = open(filename, 'w')
    fp.close()
    fp = open(filename, 'a')
    #lines 1 to 11
    fp.write("##+n# kriso container ship \n reflength %f\n grav %3.2f\n \n sym %i %i\n nhullpatches %i\n nfspatches %i\n \n nhullpoints %i\n nfspoints %i\n nhullpanels %i\n nfspanels %i\n 
(reflength ,grav,symx,symy,nhullpatches ,nfspatches ,\n nhullpoints ,nfspoints,nhullpanels ,nfspanels))
    #lines 12 to 16
    st = np.array([0])
p4 = hull(fp, origin, st, 4, 0, px4, py4, pz4, 1, 4, 0, 0, 0, 0)

p3 = hull(fp, origin, p4, 3, 1, px3, py3, pz3, 1, 3, 0,
         (0.5*fspan),(0.5*fspan)+np.shape(px3)[1]−1,489,526)

p1 = hull(fp, origin, p3, 1, 0, px1, py1, pz1, 1, 1, 0, 0, 0, 0)

p2 = hull(fp, origin, p1, 2, 1, px2, py2, pz2, 1, 2, 0,(0.5*fspan)+np.shape(px3)
         [1]−1,
         (0.5*fspan)+np.shape(px3)[1]−1+np.shape(px2)[1]−1,668,479)

p2t = hull(fp, origin, p2, 2, 1, px2t, py2t, pz2t, 1, 2, 0,(0.5*fspan)+np.shape(px2)
          [1]−1,
          (0.5*fspan)+np.shape(px2)[1]−1+np.shape(px2)[1]−1,668,479)

# lines 17 through 21

p5 = freesurf(fp, origin, st, 1, px5, py5, pz5, 1, 1, 0,(0.5*fspan),
               (0.5*fspan) + np.shape(px3)[1]−1+np.shape(px2)[1]−1,7,54)

#define st =1

st4=1

st3 = points(fp, st4, px4, py4, pz4)

st1 = points(fp, st3, px3, py3, pz3)

st2 = points(fp, st1, px1, py1, pz1)

st2t = points(fp, st2, px2, py2, pz2)

st = points(fp, st2t, px2t, py2t, pz2t)

# st is again defined as 1 for free surf

st5 =1

st = points(fp, st5, px5, py5, pz5)

#define pad arrays

lpad4 = np.zeros((np.shape(p4)[0],2))

vpad4 = np.zeros((2,np.shape(px4)[1]))

lpad3 = np.zeros((np.shape(p3)[0],2))
vpad3 = np.zeros((2, np.shape(p3)[1]))
lpad2 = np.zeros((np.shape(p2)[0], 2))
vpad2 = np.zeros((2, np.shape(p2)[1]))

lpad2t = np.zeros((np.shape(p2t)[0], 2))
vpad2t = np.zeros((2, np.shape(p2t)[1]))

lpad1 = np.zeros((np.shape(p1)[0], 2))
vpad1 = np.zeros((2, np.shape(p1)[1]))

lpad5 = np.zeros((np.shape(p5)[0], 2))
vpad5 = np.zeros((2, np.shape(p5)[1]))

# nhullpanels
panel(fp, p4, st4, lpad4, vpad4)
panel(fp, p3, st3, lpad3, vpad3)
panel(fp, p1, st1, lpad1, vpad1)
panel(fp, p2, st2, lpad2, vpad2)
tripanel(fp, p2t, st2t, lpad2t, vpad2t)
panel(fp, p5, st5, lpad5, vpad5)

fp.close()

```python
def hull(fp, origin, pst, v1, v2, x, y, z, v1_15, v2_15, v3_15, v1_16, v2_16, v3_16, v4_16):
    
    """
    INPUT:
    fp = input pan file
    origin = origin for all the patches (Global)
    pst = previous panel array(output form last panel list);
        array([0]) for first hull patch
```
781  \( v1 = \text{ID of the patch} \)
782  \( v2 = 0 \) for no water line, 1 for water line
783  \( x = x \text{ ordinates of } i \text{th panel} \)
784  \( y = y \text{ ordinates of } i \text{th panel} \)
785  \( z = z \text{ ordinates of } i \text{th panel} \)
786  \( v1_{15} = \text{ID of waterline this patch may have} \)
787  \( v2_{15} = \text{ID of hull patch this WL belongs to} \)
788  \( v3_{15} = 0 \) for WL on port side of hull; 1 for WL on Stbd side
789  \( v1_{16} = \text{index of first panel of WL} \)
790  \( v2_{16} = \text{index of last panel of WL} \)
791  \( v3_{16} = \text{index of first point of WL} \)
792  \( v4_{16} = \text{index of last point of WL} \)

\text{OUTPUT}

\text{panel list}

\text{"""}
797  h = np.shape(x)[0]
798  v = np.shape(x)[1]
799  p = np.arange(1,1+ (h-1)*(v-1)).reshape(h-1,v-1)
801  \text{# \textit{lines 12 to 16}}
802  fp.write(" hull \ %i \ %i\n %f %f %f\n %i %i %i %i\n \ \
803  %i %i %i \ %i %i %i %i\n")% (v1,v2,origin[0],origin[1],origin[2],
  pst.max()+ p[0,0],pst.max()+ p[h-2,v-2],
805  v-1,h-1,v1_15,v2_15,v3_15,v1_16,v2_16,v3_16,v4_16
  )
806  \text{return p + pst.max()}
807
808  \text{def freesurf(fp,origin,pst,v1,x,y,z,v1_20,v2_20,v3_20,v1_21,v2_21,v3_21,v4_21):}
809  \text{"""}
INPUT:

811  
fp = input pan file
origin = origin for all the patches (Global)

813  
pst = previous panel array(output form last panel list);
    arrat([0]) for first hull patch

815  
v1 = ID of the patch
x = x ordinates of i th panel
y = y ordinates of i th panel
z = z ordinates of i th panel

819  
v1_20 = ?? ID of waterline this patch may have ??
v2_20 = ?? ID of hull patch this WL belongs to??

821  
v3_20 = 0 for WL on port side of hull; 1 for WL on Stbd side
v1_21 = index of first panel of WL

823  
v2_22 = index of last panel of WL
v3_23 = index of first point of WL

825  
v4_24 = index of last point of WL

OUTPUT
panel list
"

831  
h = np.shape(x)[0]
v = np.shape(x)[1]

833  
v3_15 = 0
p = np.arange(1,1+ (h-1)*(v-1)).reshape(h-1,v-1)

835  
# lines 17 to 21
fp.write(" fs  %i
%f %f
%i %i %i
\\
%i %i %i
%i %i %i
\% (v1, origin[0], origin[1], origin[2],
    pst+ p[0,0], pst+ p[h-2,v-2],
    v-1,h-1,v1_20, v2_20, v3_20, v1_21, v2_21, v3_21, v4_21
)

64
return p + pst.max()

def points(fp, st, x, y, z):
    
    fp : file for writing pan file
    st : starting point of number of points; initially it is 1
    x, y, z : offsets

    output:
    i : next point in global points set

    x = x.flatten()
y = y.flatten()
z = z.flatten()
for j in range(len(x)):
    fp.write("%f %f %f %i\n" % (x[j], y[j], z[j], st+j))

    st = st+j+1

    return st

def panel(fp, p, st, lpad, vpad):
    
    fp : file for writing pan file
    x : offsets
    lpad: contains longitudinal panel set of adjacent patches
    vpad: contains vertical or transverse(for free surface) set of panels of adjacent patches
    p: panel number file
    k: start index

    return st
# correction for the points list

```python
st = st - p[0,0] + 1

for i in range(np.shape(p)[0]):
    for j in range(np.shape(p)[1]):
        if i == 0:
            if j == 0:
                v6 = lpad[i,0]
                v7 = p[i,j+1]
                v8 = p[i+1,j]
                v9 = vpad[0,j]
            elif j == np.shape(p)[1]-1:
                v6 = p[i,j-1]
                v7 = lpad[i,1]
                v8 = p[i+1,j]
                v9 = vpad[0,j]
            else:
                v6 = p[i,j-1]
                v7 = p[i,j+1]
                v8 = p[i+1,j]
                v9 = vpad[0,j]
        elif i == np.shape(p)[0]-1:
            if j == 0:
                v6 = lpad[i,0]
                v7 = p[i,j+1]
                v8 = vpad[1,j]
                v9 = p[i-1,j]
            elif j == np.shape(p)[1]-1:
                v6 = p[i,j-1]
                v7 = lpad[i,1]
                v8 = vpad[1,j]
                v9 = p[i-1,j]
```

66
else:
    v6 = p[i, j-1]
    v7 = p[i, j+1]
    v8 = vpad[1, j]
    v9 = p[i-1, j]
else:
    if j == 0:
        v6 = lpad[i, 0]
        v7 = p[i, j+1]
        v8 = p[i+1, j]
        v9 = p[i-1, j]
    elif j == np.shape(p)[1]-1:
        v6 = p[i, j-1]
        v7 = lpad[i, 1]
        v8 = p[i+1, j]
        v9 = p[i-1, j]
    else:
        v6 = p[i, j-1]
        v7 = p[i, j+1]
        v8 = p[i+1, j]
        v9 = p[i-1, j]

    fp.write("%i %i %i %i %i %i %i %i %i
    (p[i, j]+i+st-1,p[i, j]+np.shape(p)[1]+st+i,\
    p[i, j]+np.shape(p)[1]+st+1+i,\
    p[i, j]+st+i,p[i, j],v6,v7,v8,v9))

def tripanel(fp, p, st, lpad, vpad):
    ""
    fp : file for writing pan file
    x : offsets
    ""
lpad: contains longitudinal panel set of adjacent patches
vpad: contains vertical or transverse (for free surface) set of panels of adjacent patches

p: panel number file
k: start index

""
#correction for the points list
st = st−p[0,0]+1
for i in range(np.shape(p)[0]):
    for j in range(np.shape(p)[1]):
        if i == 0:
            if j == 0:
                v6 = lpad[i,0]
                v7 = lpad[i,1]
                v8 = p[i+1,j]
                v9 = vpad[0,j]
            elif j == np.shape(p)[1]−1:
                v6 = lpad[i,0]
                v7 = lpad[i,1]
                v8 = vpad[1,j]
                v9 = p[i−1,j]
        else:
            v6 = lpad[i,0]
            v7 = lpad[i,1]
            v8 = p[i+1,j]
            v9 = p[i−1,j]
        fp.write("%i %i %i %i %i %i %i %i\n" "%i %i %i %i %i %i %i %i\n"
(p[i,j]+i+st−1,p[i,j]+np.shape(p)[1]+st+i,\n p[i,j]+np.shape(p)[1]+st+1+i,\n p[i,j]+st+i,p[i,j],v6,v7,v8,v9))
"""
def lcbrange(LCB, L):

    if ((-0.03*L <= LCB)&(LCB <= 0.03*L)):
        g = 0.
    else:
        # constraint is violated
        print 'exceeded'
        g = abs(LCB) - 0.03

    return g

### Nelder-Mead simplex algorithm
### Original routine is from scipy/optimize/optimize.py version 0.7 by
### Travis E. Oliphant
### last update: 090906, lb

import numpy

from numpy import atleast_1d, eye, mgrid, argmin, zeros, shape, empty, \
    squeeze, vectorize, asarray, absolute, sqrt, Inf, asfarray, isinf

# helper function

def wrap_function(function, args):
    ncalls = [0]

    def function_wrapper(x):
        ncalls[0] += 1
        return function(x, *args)

    return ncalls, function_wrapper

def nmsimplex(func, x0, nondelt, zdelt, xtol=1e-4, args=(), ftol=1e-4, \
    maxiter=None, maxfun=None,
```python
    full_output=0, disp=1, retall=0, callback=None):
        
        Minimize a function using the downhill simplex algorithm.
        
        Parameters:
        
        func : callable func(x,*args)
            The objective function to be minimized.
        x0 : ndarray
            Initial guess.
        args : tuple
            Extra arguments passed to func, i.e. ‘f(x,*args)’.
        callback : callable
            Called after each iteration, as callback(xk), where xk is the
            current parameter vector.
        
        :Returns: (xopt, {fopt, iter, funcalls, warnflag})
        
        xopt : ndarray
            Parameter that minimizes function.
        fopt : float
            Value of function at minimum: ‘fopt = func(xopt)’.
        iter : int
            Number of iterations performed.
        funcalls : int
            Number of function calls made.
        warnflag : int
            1 : Maximum number of function evaluations made.
            2 : Maximum number of iterations reached.
        allvecs : list
            Solution at each iteration.
```
*

Other Parameters*:

- **xtol**: float
  Relative error in xopt acceptable for convergence.

- **ftol**: number
  Relative error in func(xopt) acceptable for convergence.

- **maxiter**: int
  Maximum number of iterations to perform.

- **maxfun**: number
  Maximum number of function evaluations to make.

- **full_output**: bool
  Set to True if fval and warnflag outputs are desired.

- **disp**: bool
  Set to True to print convergence messages.

- **retall**: bool
  Set to True to return list of solutions at each iteration.

:Notes:

Uses a Nelder–Mead simplex algorithm to find the minimum of function of one or more variables.

```python
f, func = wrap_function(func, args)
x0 = asarray(x0).flatten()
N = len(x0)
rank = len(x0.shape)
if not -1 < rank < 2:
    raise ValueError, "Initial guess must be a scalar or rank-1 sequence."
if maxiter is None:
    maxiter = N * 200
```


if maxfun is None:
    maxfun = N * 200

rho = 1; chi = 2; psi = 0.5; sigma = 0.5;
one2np1 = range(1,N+1)

if rank == 0:
    sim = numpy.zeros((N+1,), dtype=x0.dtype)
else:
    sim = numpy.zeros((N+1,N), dtype=x0.dtype)
fsim = numpy.zeros((N+1,), float)
sim[0] = x0
if retall:
    allvecs = [sim[0]]

# The initial design is evaluated
fsim[0] = func(x0)

## nonzdel = 0.05  # default value for creating initial simplex
## zdelt = 0.00025  # default value if x_k==0

# Loop over N additional design for initial simplex
for k in range(0,N):
    y = numpy.array(x0,copy=True)
    if y[k] != 0:
        y[k] = (1+nonzdel)*y[k]
    else:
        y[k] = zdelt
# Add new design to simplex and evaluate it

```python
sim[k+1] = y
f = func(y)
fsim[k+1] = f

ind = numpy.argsort(fsim)
fsim = numpy.take(fsim, ind, 0)
# sort so sim[0,:) has the lowest function value
sim = numpy.take(sim, ind, 0)

iterations = 1

while (fcalls[0] < maxfun and iterations < maxiter):
    if (max(numpy.ravel(abs(sim[1:] - sim[0]))) <= xtol \
        and max(abs(fsim[0] - fsim[1:])) <= ftol):
        break

    xbar = numpy.add.reduce(sim[:-1], 0) / N
    xr = (1+rho)*xbar - rho*sim[-1]
    fxr = func(xr)
    doshrink = 0

    if fxr < fsim[0]:
        xe = (1+rho*chi)*xbar - rho*chi*sim[-1]
        fxe = func(xe)

        if fxe < fxr:
            sim[-1] = xe
            fsim[-1] = fxe
        else:
            sim[-1] = xr
```

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fsim[-1] = fxr

else: # fsim[0] <= fxr
    if fxr < fsim[-2]:
        sim[-1] = xr
        fsim[-1] = fxr

else: # fxr >= fsim[-2]
    # Perform contraction
    if fxr < fsim[-1]:
        xc = (1 + psi*rho)*xbar - psi*rho*sim[-1]
        fxc = func(xc)

        if fxc <= fxr:
            sim[-1] = xc
            fsim[-1] = fxc
        else:
            doshrink = 1

else:
    # Perform an inside contraction
    xcc = (1 - psi)*xbar + psi*sim[-1]
    fxcc = func(xcc)

    if fxcc < fsim[-1]:
        sim[-1] = xcc
        fsim[-1] = fxcc
    else:
        doshrink = 1

if doshrink:
    for j in one2np1:
        sim[j] = sim[0] + sigma*(sim[j] - sim[0])
        fsim[j] = func(sim[j])
ind = numpy.argsort(fsim)
sim = numpy.take(sim, ind, 0)
fsim = numpy.take(fsim, ind, 0)
if callback is not None:
    callback(sim[0])
iterations += 1
if retall:
    allvecs.append(sim[0])

x = sim[0]
fval = min(fsim)
warnflag = 0

if fcalls[0] >= maxfun:
    warnflag = 1
    if disp:
        print "Warning: Maximum number of function evaluations has \\
"    "been exceeded."
elif iterations >= maxiter:
    warnflag = 2
    if disp:
        print "Warning: Maximum number of iterations has been exceeded"
else:
    if disp:
        print "Optimization terminated successfully."
        print "Current function value: \%f" % fval
        print "Iterations: \%d" % iterations
        print "Function evaluations: \%d" % fcalls[0]
if full_output:
    retlist = x, fval, iterations, fcalls[0], warnflag

    if retall:
        retlist += (allvecs,)

else:
    retlist = x

    if retall:
        retlist = (x, allvecs)

return retlist

if __name__ == "__main__":

    Vsa = np.array(range(15,34))
    alphaa = np.zeros(len(Vsa))
    alphaa[:] = 0.8

    for i in range(len(Vsa)):
        Vs = Vsa[i]
        alpha = alphaa[i]

    Lpp = 230.  # Lenght between perpendiculars [m]
    Lwl = 233.58  # Lenght on Load water line [m]
    B = 32.2  # Breadth [m]
    T = 10.8  # Draft [m]
    Ch = 0.6505  # Block Coefficient of Fineness
    Pf = 0.  # extent of forward paralled middle body
    Pa = 0.  # extent of aft paralled middle body
    v = 11  # number of panels girthwise
    vl = 6  # number of stern tube panels girthwise
vu = v - v1  # number of transom patch panels girthwise

v_fs = 20  # number of free surface panels width wise

# fspan = Number of panels for one length [even number]

fspan = 30  # number of free surface points per ship length

# number of panels on each patch (length wise)

npan1 = 5
npan2 = 8
npan3 = 44
npan4 = 6

delta_s = 0.015  # defines initial Free surface panel width

w_beta = 1.05  # defines rate of increase in free surface panel widths

# sideways

# factor for calculating the freeboard, 0.5 to 0.7

alpha = 0.2

# beta = alpha / no of panels length wise

beta = alpha / (npan1+npan2+npan3)

# end sealing

# stern boss closing point

sx = 5.405
sy = 0.
sz = 4.1

# transom closing

tx = -2.43
ty = 0.0
tz = 10.80

# bulb closing

bx = 237.083
by = 0.
bz = 5.876
Atp = 1.0
Ftp = 1.0

# pan file name:
filename = 'hull_SFB.pan'

# Call the function to read the offsets and Station spacing
xlong, offsets, yst, zst, Across, Girth = readoffsets("kcs.body.txt", T)
sta = range(0, 57)
origin = [0, 0, 0] # Global origin for all the points and patches

# Generation of hull patch offset data
x1, y1, z1 = patch(xlong, offsets, sta[6:12], 1, vl, vl, vl, vu, sx, sy, sz, tx, ty, tz, bx, by, bz, beta, Lpp, T)
x2, y2, z2 = patch(xlong, offsets, sta[2:12], 2, vu, vu +1, vl, vu, sx, sy, sz, tx, ty, tz, bx, by, bz, beta, Lpp, T)
x3, y3, z3 = patch(xlong, offsets, sta[11:49], 3, v, v+1, vl, vu, sx, sy, sz, tx, ty, tz, bx, by, bz, beta, Lpp, T)
x4, y4, z4 = patch(xlong, offsets, sta[48:57], 4, vl, vl, vl, vu, sx, sy, sz, tx, ty, tz, bx, by, bz, beta, Lpp, T)

# WL aft most point, WL fwd most point
WL = [-2.43, 233.58]

# Point of fwd of Bulbous bow
xBlb = 237.083

# Transom Patch
zone1 = [WL[0], xBlb, x1[0, -1], x1[0, 0]]
zone2 = [WL[0], xBlb, x2[0, -1], x2[0, 0]]
zone3 = [WL[0], xBlb, x3[0, -1], x3[0, 0]]
zone4 = [WL[0], xBlb, x4[0, -1], x4[0, 0]]

pandist = np.array([[−1.0, 0., 1.0], [
    0.1, 1.0, 0.1]])

nx1, ny1, nz1 = stainterp(xlong, zone1, pandist, npan1, x1, y1, z1)
nx2, ny2, nz2 = stainterp(xlong, zone2, pandist, npan2, x2, y2, z2)
nx3, ny3, nz3 = stainterp(xlong, zone3, pandist, npan3, x3, y3, z3)
nx4, ny4, nz4 = stainterp(xlong, zone4, pandist, npan4, x4, y4, z4)

desc = 0
if np.any(np.diff(nx3[0]) < 0):
    desc = 1
    pos = np.searchsorted(nx2[0][::−1], −.8)

# for aft triangular patch
nx2t = np.array([[nx2[0, len(nx2[0])−pos], nx2[0, −1]], [
    [nx2[−2, len(nx2[0])−pos], nx2[−2, −1]], [
    [nx2[−1, len(nx2[0])−pos], nx2[−1, −1]]],
ny2t = np.array([[ny2[0, len(nx2[0])−pos], ny2[0, −1]], [
    [ny2[−2, len(nx2[0])−pos], ny2[−2, −1]], [
    [ny2[−1, len(nx2[0])−pos], ny2[−1, −1]]],
nz2t = np.array([[nz2[0, len(nx2[0])−pos], nz2[0, −1]], [
    [nz2[−2, len(nx2[0])−pos], nz2[−2, −1]], [
    [nz2[−1, len(nx2[0])−pos], nz2[−1, −1]]],

nx2 = nx2[::1−pos]
ny2 = ny2[::1−pos]
nz2 = nz2[::1−pos]
else:
    pos = np.searchsorted(nx2[0], -.8)
    nx2 = nx2[:, pos:]
    ny2 = ny2[:, pos:]
    nz2 = nz2[:, pos:]

    # Correction for Free board straight panel half breadths
    # Correction by Dr. Birk on 18 Nov 09
    ny2t[-1] = ny2t[-2]
    ny2[-1] = ny2[-2]
    ny3[-1] = ny3[-2]

    # Waterline panel points
    nxwl = np.append(nx3[-1], nx2[-1][1:])
    nxwl = np.append(nxwl, nx2t[-1][1:])
    nywl = np.append(ny3[-1], ny2[-1][1:])
    nywl = np.append(nywl, ny2t[-1][1:])

    nx5, ny5, nz5 = patchfs(nxwl, nywl, fspan, v_fs, T, Lpp, Lwl, delta_s, beta, w_beta)

    ### initial guess of change in LCB
    x0 = -0.05

    # Controlling the size of the Initial simplex
    nonzdelt = 0.05
    zdelt = 0.00025
    xtol = 1.e-5

    # control file for panel code
    fp = open('nlhsfsctrl.in', 'w')
    fp.close()

    fp = open('nlhsfsctrl.in', 'a')
fp.write('# This is a control file for hsfs
')
1335 fp.write(filename)
1337 fp.write('nflow.dat
')
1339 fp.write('sigma.vtp\n')
1341 fp.write('hulls\n')
1343 fp.write('hullsm.vtp\n')
1345 fp.write('hullv.vtu\n')
1347 fp.write('fss\n')
1349 fp.write('fssm.vtp\n')
1351 fp.write('waveprof\n')
1353 fp.write('1 # linear free surface; double body flow=0
')
1355 fp.write('0
')
1357 fp.write('0.8
')
1359 fp.write('%f #Froude number (design speed) \n % (Vs*0.5144/(9.81*Lpp)**0.5)
')
1361 fp.close()
1363
fp = open("optimization"+str(Vs)+'_'+str(alpha)+".dat", 'w')
1365 fp.close()
1367 ## resistance(-0.033056478)
nmsimplex(resistance ,x0 ,nonzdelt ,zdelt ,xtol)
1369
fp = open("optimization"+str(Vs)+'_'+str(alpha)+".dat", 'r')
1371 lines = fp.readlines()
1373 fp.close()
1375
nLCB = []
1377 nR = []
1379
for line in lines:
nLCB. append( float( line.split()[0]) )
nR. append( float( line.split()[1]) )

nLCB = np.asarray(nLCB)
nR = np.asarray(nR)

## leg = plt.scatter(nLCB,nR)
## for i in range(len(nLCB)):
## i = str(i)
## plt.text(nLCB[i], nR[i], i)
## plt.plot(nLCB,nR, '.')
## plt.title('Speed = '+str(Vs)+' Knots')
## plt.xlabel(r'Position of LCB from midships')
## plt.ylabel(r'Coefficient of Wavemaking Resistance')
##
## plt.text(max(nLCB),max(nR),'Cw = '+str(min(nR))[:10]+"
\nLCB = '+str(50*nLCB[np.argmin(nR)])[10],
verticalalignment='top', horizontalalignment='right', fontsize=15)
## plt.grid()
## plt.savefig(str(Vs)+' knots '+str(alpha)+' alpha.png')
## plt.close()

fp = open('results.dat', 'a')
fp.write( '%f %f %12.12f %12.12f
' % (Vs, alpha, nLCB[np.argmin(nR)], min(nR)))
fp.close()
Vita

Krishna Murthy Karri, born in Hyderabad, India, graduated in May 2008 from Andhra University College of Engineering, Visakhapatnam, India, with a Bachelors (Honors) degree in Naval Architecture. Immediately upon completion of the undergraduate degree, he enrolled in the graduate program at the University of New Orleans, where he is currently a candidate for Master of Science degree in Naval Architecture and Marine Engineering. He is currently working as an intern in Technology Associates INC, New Orleans, and after successful completion of Masters degree he will work as a Naval Architect.