PYTHON BASED NAVAL ARCHITECTURE TOOLS

PyNAT

Theory and Validation

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Contents

1 Introduction

Python based Naval Architecture tools (PyNAT) is a Library of python scripts to perform hydrostatic and stability analysis of a hull form defined by curve points of transverse sections

The following are the salient features:

- Compute hydrostatics at given drafts and trims
- Compute KN curves at given heel angles for a range of displacements
- Compute GZ curve for given KG and displacement
- Use spline to fit curves and integrate to obtain areas and moments

2 Methodology:

2.1 Hull Geometry Definition:

- The Hull geometry is defined by station wise curve points
- The hull is assumed to be symmetric and only port side half is defined
- The given ship hull surface is intersected with Transverse planes along the length and the corresponding section curves are obtained.
- Key points on the section curve are identified and the corresponding offsets are used to define the section curves
- Provision to define Knuckle points and section curve discontinuity is provided through a parameter

The reference system to measure the coordinates of curve points is shown in fig (1)

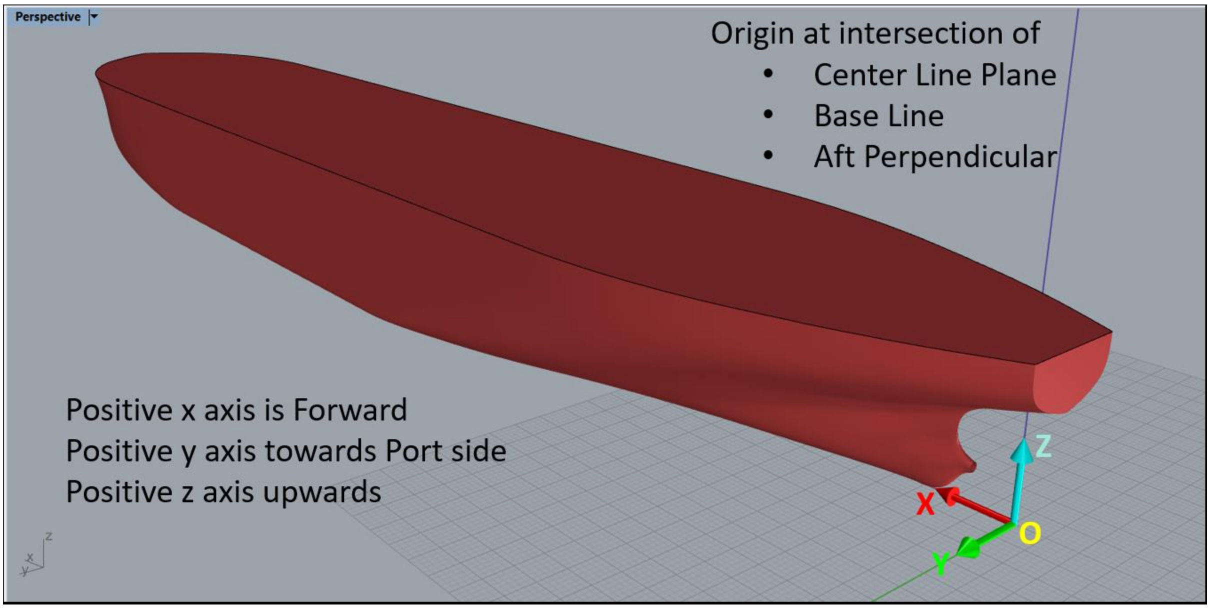


Fig 1. Reference System for Ship Geometry Definition

2.2 B-Spline Curve Fitting:

A Basis Spline curve is fitted to the curve points corresponding to each of the section curves.

For a section curve passing through 'n+1' curve points given by,

$$P_0, P_1, P_2 \dots \dots \dots \dots P_n$$

Any point on the curve can be expressed as linear combination of the curve points and the B-Spline basis functions given by,

$$r(t) = \sum_{i=0}^{n} P_i \, N_{i,k}(t) \qquad n \geq k-1 \, ; t \in [t_{k-1}, t_{n+1}] \tag{1}$$

Here,

t is the parameter corresponding to any point along the curve,

$N_{i,k}$ (t) are the basis functions which are defined over the knot vector,

$$T = [t_0, t_1, \dots, t_{k-1}, t_k, t_{k+1}, \dots, t_{n-1}, t_n, t_{n+1}, \dots, t_{n+k}] \tag{2}$$

The basis function is evaluated using the following expressions,

$$N_{i,1}(t) = \begin{cases} 1 & for \; t_i \leq t < t_{i+1} \\ 0 & otherwise \end{cases} \tag{3a}$$

$$N_{i,k}(t) = \frac{t-t_i}{t_{i+k-1}-t_i} N_{i,k-1}(t) + \frac{t_{i+k}-t}{t_{i+k}-t_{i+1}} N_{i+1,k-1}(t) \tag{3b}$$

Here k is the order of the fit, and k-1 is the degree

2.3 Computing Hydrostatics

The Area properties of a half section at x and draft d are obtained by integrating over each section using the following formula,

Area of half section,

$$HAr(x,d) = \int_0^d y \, dz \tag{4}$$

Vertical moment of half section,

$$HVM(x,d) = \int_0^d yz \, dz \tag{5}$$

Transverse Moment of half section,

$$HTM(x,d) = \int_0^d y^2 \, dz \tag{6}$$

Girth length of half section,

$$HGL(x,d) = \int_0^d \sqrt{1 + \frac{dy}{dz}} \; .dz \tag{7}$$

Note: In the above expressions y is a function of z

y is the corresponding offset at draft level z for a section at x

The Hull Hydrostatics are obtained by the following formulae,

Underwater volume,

$$VOL(d) = 2\int_{x_{aft}}^{x_{fwd}} HAr(x,d) \, .dx \tag{8}$$

Displacement,

$$DISP(d) = 1.024 * VOL(d) \tag{9}$$

Wetted surface area,

$$WSA(d) = 2\int_{x_{aft}}^{x_{fwd}} HGL(x,d) \, .dx \tag{10}$$

Longitudinal centre of buoyancy,

$$LCB(d) = \frac{2}{VOL(d)}\int_{x_{aft}}^{x_{fwd}} x \, .dx \tag{11}$$

Vertical centre of buoyancy,

$$VCB(d) = \frac{2}{VOL(d)}\int_{x_{aft}}^{x_{fwd}} HVM(x,d) \, .dx \tag{12}$$

Water Plane Area,

$$WPA(d) = \int_{x_{aft}}^{x_{fwd}} y \, .dx \tag{13}$$

Longitudinal Centre of Flotation,

$$LCF(d) = \frac{2}{WPA(d)}\int_{x_{aft}}^{x_{fwd}} xy \, .dx \tag{14}$$

Transverse Metacentric radius,

$$BMT(d) = \frac{2}{3*VOL(d)} \int_{x_{aft}}^{x_{fwd}} y^3 . dx \tag{15}$$

Longitudinal Metacentric radius,

$$BML(d) = \frac{2}{VOL(d)} \int_{x_{aft}}^{x_{fwd}} y(x - LCF)^2 . dx \tag{16}$$

Transverse Metacentric Height,

$$GMT(d) = BMT(d) + VCB(d) - KG \tag{17}$$

Longitudinal Metacentric Height,

$$GML(d) = BML(d) + VCB(d) - KG \tag{18}$$

Tonnes per centimetre immersion,

$$TPC(d) = WPA(d) * 1.024 * \frac{1}{100} \tag{19}$$

Moment to change trim by one centimetre,

$$MCT(d) = \frac{DISP(d)*BML(d)}{100*L} \tag{20}$$

2.4 Computing KN Data

For a ship hull floating at a particular draft and heel, KN is the length of perpendicular from centreline keel point ‘K’ on to the Line of action of buoyancy. See fig 2.

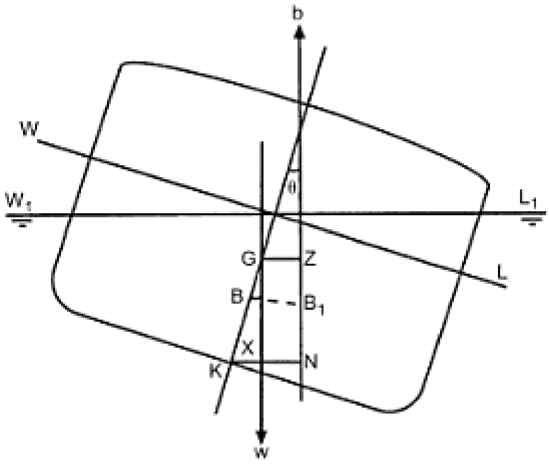


Fig 2: KN Definition

For each heel angle the limiting minimum and maximum possible drafts at centreline are obtained for the entire hull using an iterative technique. An evenly spaced range of centreline drafts are generated for each heel angle.

First the section wise calculations are performed to obtain required area properties at various heel angles over a range of drafts. At each heel angle and centreline draft, for a given section, the port and starboard point of intersections of the section curve with the water line are computed using an iterative algorithm.

Once the Starboard and port intersections are obtained, the underwater section area and its moment about centreline, baseline, and midship are computed by the following expressions,

$$A(x,\phi,d) = \int_{z_{min}}^{z_{max}} (y_p - y_s)dz \tag{21}$$

$$TM(x,\phi,d) = \int_{z_{min}}^{z_{max}} 0.5(y_p - y_s)(y_p + y_s)dz \tag{22}$$

$$VM(x,\phi,d) = \int_{z_{min}}^{z_{max}} (y_p - y_s)zdz \tag{23}$$

$$LM(x,\phi,d) = A(x,\phi,d) * x \tag{24}$$

For each particular heel angle and draft, the sectional areas and moments are integrated along the length of the ship to obtain the underwater volume and the offsets of the centre of buoyancy of the ship,

$$Vol(\phi, d) = \int_{X_{aft}}^{X_{fwd}} A(x, \phi, d)dx \tag{25}$$

$$TCB(\phi, d) = \int_{X_{aft}}^{X_{fwd}} TM(x, \phi, d)dx \tag{26}$$

$$VCB(\phi, d) = \int_{X_{aft}}^{X_{fwd}} VM(x, \phi, d)dx \tag{27}$$

$$LCB(\phi, d) = \int_{X_{aft}}^{X_{fwd}} LM(x, \phi, d)dx \tag{28}$$

At a given floating condition (ϕ, d), Coordinates of point B are given by

B (LCB+LBP/2, TCB, VCB)

To find the coordinates of point N (x_N, y_N, z_N) the following expression are used,

$$m = \tan(\frac{\pi}{2} - \phi) \tag{29}$$

$$c = VCB(\phi, d) - TCB(\phi, d) * m \tag{30}$$

$$x_n = x \tag{31}$$

$$z_N = \frac{c}{1+m^2} \tag{32}$$

$$y_N = -m * z_N \tag{33}$$

The KN corresponding to each heel and draft is obtained by the following formula,

$$KN(\phi, d) = \sqrt{y_N^2 - z_N^2} \quad (34)$$

2.5 Computing GZ Curve Data

For a given floating condition defined by KG and displacement, the GZ is computed by the following expression,

$$GZ(\phi, d) = KN(\phi, d) - KG * \sin(\phi) \quad (35)$$

3 Implementation:

The methodology described in the earlier section is implemented by scripting classes in python. Object oriented paradigm is chosen to systematically group the data and the operations pertaining to it. This gives the following advantages,

- Efficient design of algorithm
- Efficient implementation
- Reusability of routines
- Improves readability of script
- Ease of further development

The following External Libraries are used:

1. NUMPY
2. SCIPY
3. MATPLOTLIB

3.1 Evaluation of integrals:

The analysis requires integration of functions over the immersed depth of the section and the length of the ship.

In order to perform the integration numerically,

- Generated a range of values for integrating variable with in the integration limits
- Function values are evaluated at each value in the range of integrating variable.
- A spline curve is fitted to the Function values and the corresponding values of Integrating variable
- The spline curve is integrated using either the ***scipy.integrate.quad*** function or the ***scipy.interpolate.splint***

3.2 Input files:

Table 1 : Description of input files

File Name	Type of Input Data
Set_EP.dat	Environmental Parameters
Set_HG.dat	Hull Geometry Definition
Set_HS.dat	Case List for Hydrostatic analysis
Set_KN.dat	Case List for KN Computations
Set_LC.dat	Load Cases for Large Angle stability (GZ)

3.3 Python Script files:

Table 2 : Description of python script files

File Name	Script Purpose
PyNAT.py	Main Execution Script
FileSystem.py	Directory structure and file paths
ENV_PROP.py	Environment parameters
HullGeometry.py	Hull Geometry Definition Processing
SectionCurves.py	Section Curve fitting data
HydroStatics.py	Hydrostatic analysis and data
LAS_KN_xx.py	Cross curves of stability data and analysis
LAS_GZ	Large angle stability (GZ) analysis and data

PyNAT.py:

This is the main script that is executed at the beginning. No class is defined in this script.

This module preforms the following operations

- Import necessary modules
- Create a File System Object and create necessary directories
- Create an environment properties data object
- Create a Hull Geometry Object
- Initiate a loop to prompt user to choose an analysis to perform
- Based on the user choice, the corresponding analysis object is created and functions are called to perform the analysis

ENV_PROP.py:

Defines a class to hold the environment data, in the current case only the density of water.

Up on initialization of a class object, water density is read from the corresponding input file.

FileSystem.py:

Contains a class that holds standard directory names and the full file names to read and write data. When a new project is initiated the File System object deletes old output data and creates required directories.

HullGeometry.py:

Class object contains the following data:

- Main Dimension
- Hull section curve points and the corresponding Section Curve data object

The following function are defined:

- _init_() :
    - constructor calls readFromFile(), writeToFile()
    - sets tolerance
- readFromFile()
    - To read the Hull geometry data from the input file
    - Sort and refine the read data
    - Create Section Curve data objects
- writeToFile()
    - Writes the Data to output file
    - Plot the Section in a body plan view and save image

HydroStatics.py:

The class object contains the following data:

- Hydrostatic parameters over a given range of drafts and trims

Following functions are defined in the class:

- _init_ ():
    - Constructor
    - Calls the relevant local functions to perform the hydrostatic analysis
- readFromFile():
    - Reads the draft and trim data from the input file
    - Computes sectional drafts for each floating case
- computeSectionalHydroStatics():
    - Computes section wise hydrostatic data at the predetermined drafts
    - Integration of various parameters over the section curve is performed
- computeHullHydroStatics():
    - Integrates the sectional data to obtain the hull hydrostatics
- writeSectionalHydrostaticsToFile():
    - Writes the sectional hydrostatic data to the output file

- writeHullHydrostaticsToFile():
    - Appends the Hydrostatic data to that same output file

LAS_KN_xx.py:

The class object contains the following data:

- KN values for each heel angle over a range of displacements

Following functions are defined in this class:

- _init_ ()
    - The constructor that calls other local functions to perform the computations
- readFromFile()
    - Reads the Heel angles from the input files
- compute()
    - Compute the KN values for each combination of heel angle and draft/ displacement by implementing the methodology described earlier.
- writeToFile()
    - Writes the KN data to a file in tabular format
    - Plots the cross curves of stability and save the image to file

LAS_GZ.py:

The class object contains the GZ data over a range of heel angles, for each floating conditions

Following functions are defined in the class:

- _init_()
    - The constructor that calls other functions to perform GZ analysis
- readFromFile()
    - Reads the load cases from the input file : The mass displacement and the KG values for each load case
- compute()
    - Computes the GZ values for each load case over a range of heel angles
- writeToFile()
    - Writes the GZ data to a file
    - Plots the GZ curves and saves the images to file

3.4 Output Files:

Output files are written in sub directories located in the directory “out”. The following sections describe the

3.5 Output files in Directory "out/secs":

File Name	Content
Res_HG.dat	Hull Geometry definition and Spline Fit Data for each section curve
Body_Plan.png	The Body Plan plot showing the Spline curves plotted over the input curve points

3.6 Output files in Directory "out/hs":

File Name	Content
HS_VolDisp.png	Volumetric Displacement vs Draft
HS_MassDisp.png	Mass Displacement vs Draft
HS_WetArea.png	Wetted Hull Surface Area vs Draft
HS_LCB.png	Longitudinal Center of buoyancy from amidships (Positive forward) vs draft
HS_TCB.png	Transverse Center of buoyancy from Center Plane vs draft
HS_VCB.png	Vertical Center of Buoyancy from Base Line vs draft
HS_WPA.png	Water Plane Area vs Draft
HS_LCF.png	Longitudinal Center of Flotation vs draft
HS_BML.png	Longitudinal Metacentric Radius vs Draft
HS_BMT.png	Transverse Metacentric Radius vs Draft
HS_KML.png	Long. Metacenter height from Keel vs Draft
HS_KMT.png	Trans. Metacenter height from Keel vs Draft
HS_TPC.png	Tons per CM immersion vs draft
Res_HS.dat	The results of Hydrostatic Analysis Section wise followed by Volumetric Properties
Sect_Areas.png	Sectional Area vs Draft
Sect_Girth.png	Section Girth vs Draft
Sect_TransMom.png	Half Section Transverse moment vs Draft
Sect_VertMom.png	Section Vertical moment vs Draft
Sect_YCent.png	Y ordinate of centroid of half section from Center Line vs draft
Sect_ZCent.png	Z ordinate of centroid of section from Base Line vs draft

3.7 Output files in Directory "out/las":

File Name	Content
Res_KN.dat	The KN Curve Calculation Data (from Direct Method)
Res_GZ.dat	The GZ Curve Calculation Data (Direct Method)
Res_KN_FAST.dat	The KN Curve Calculation Data (Fast Method)
Res_GZ_FAST.dat	The GZ Curve Calculation Data (Fast Method)

4 Validation - Test Case:

KRISO KVLCC2 Hull form is used for testing the developed script. The results are validated using the commercial software, Maxsurf.

4.1 KVLCC2 Hull Geometry:

Table 3: The Main Dimensions

LBP	320 m
LWL	325.5 m
B	58 m
D	30 m
T (Design)	20.8 m
Displacement	312622 ton
Wetted Hull Area	27194 m^2
LCB (+vs Fwd midship)	3.48 %
CB	0.81
CM	0.998

4.2 PyNAT Geometry Model:

The geometry of the hull is show in the figures. A total of 23 sections were considered along the hull surface and at each station key points on the section curve are identified. The offsets of the curve points are formatted into the Hull Geometry input file.

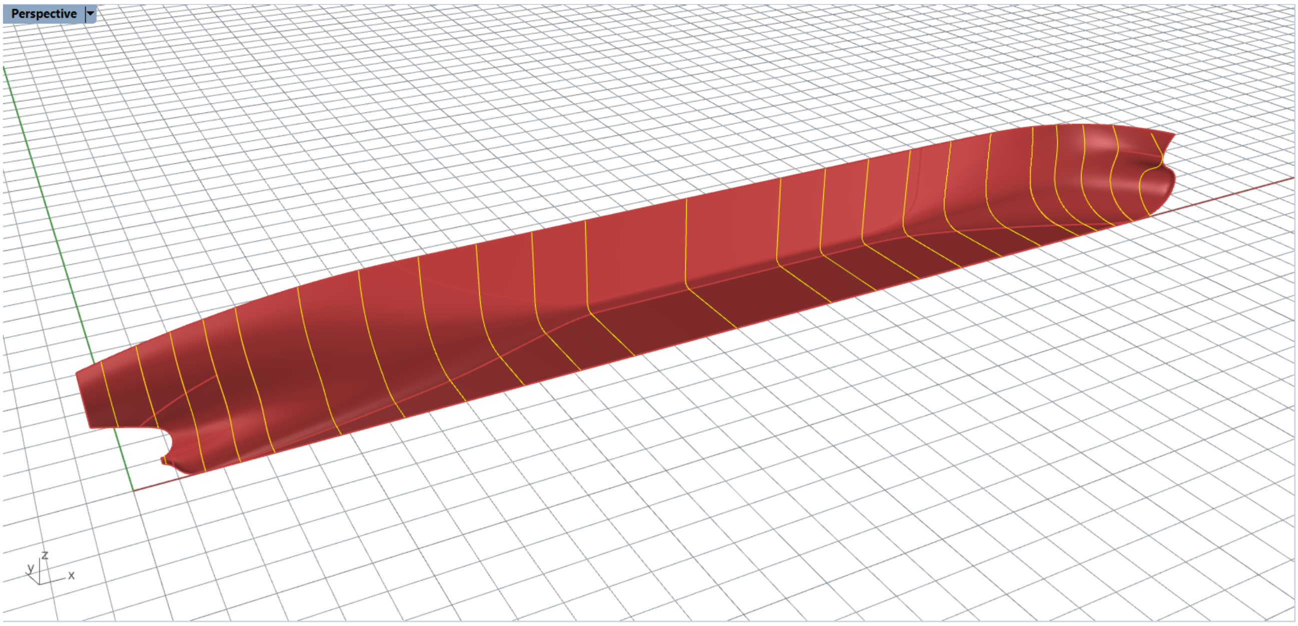
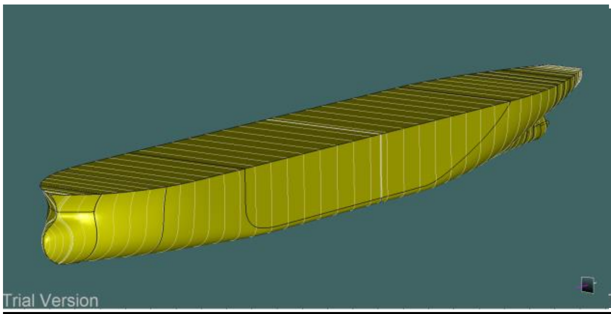
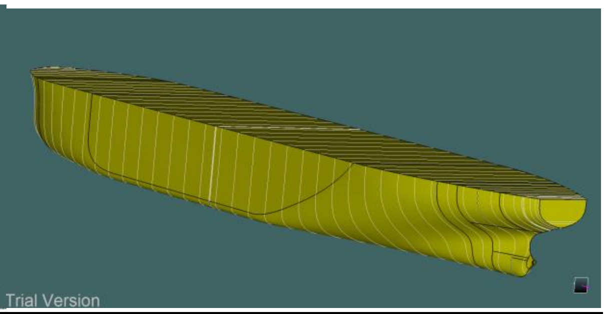


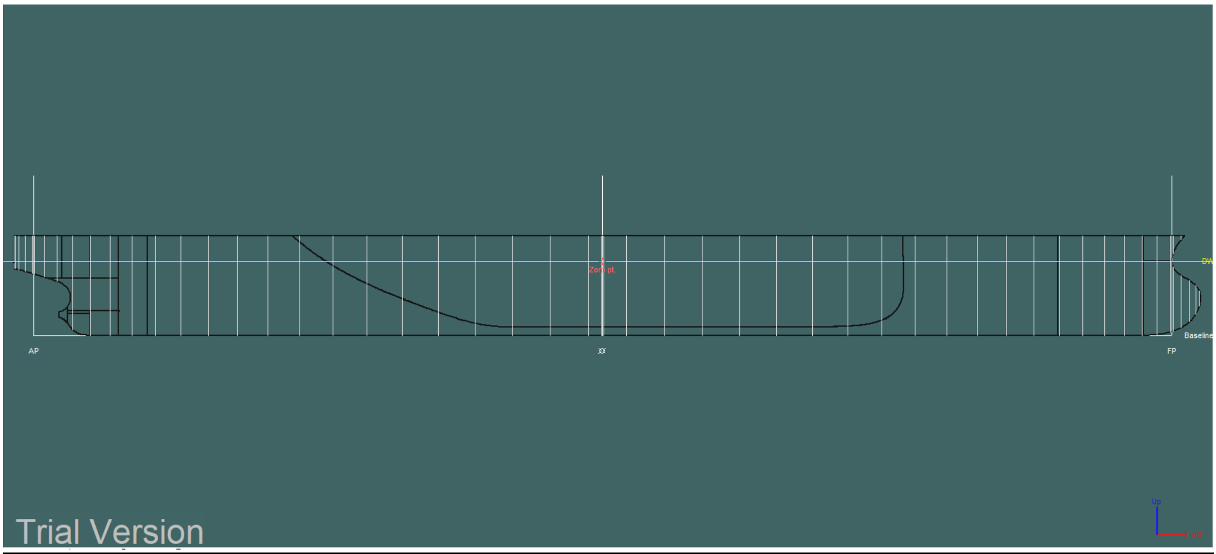
Fig 3: The Transverse section used for Python script based analysis

4.3 Maxsurf Geometry Model:

Computations are performed by using approximately 60 transverse sections along the length of the hull. The below images show the hull geometry model used for MAXSURF computations.







4.4 Results:

4.4.1 Body plan Plot

The following plots show the python script results compared with commercial software.

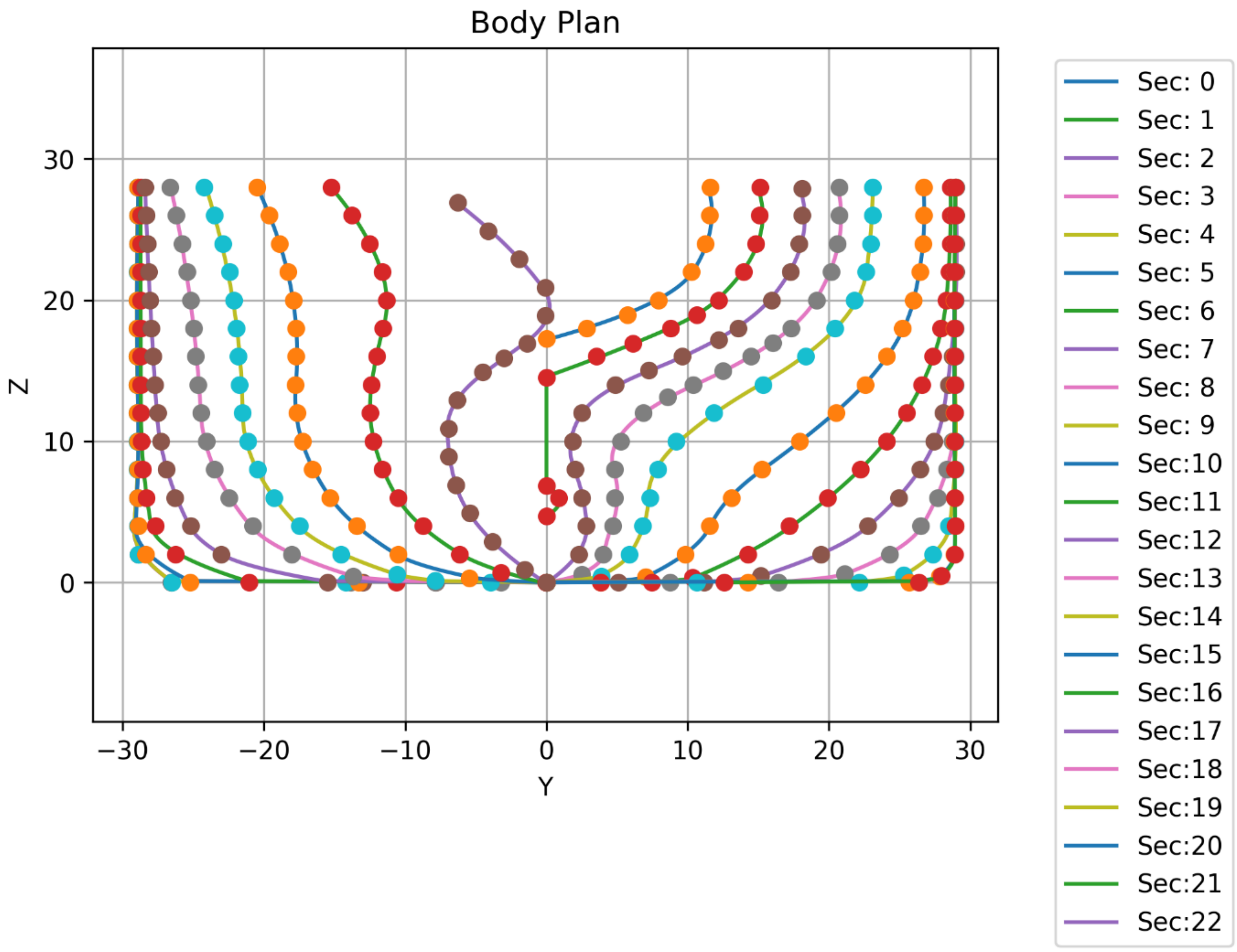


Fig 4. Python Script Output: The Body Plan plot showing Spline curves fitted to the Curve points

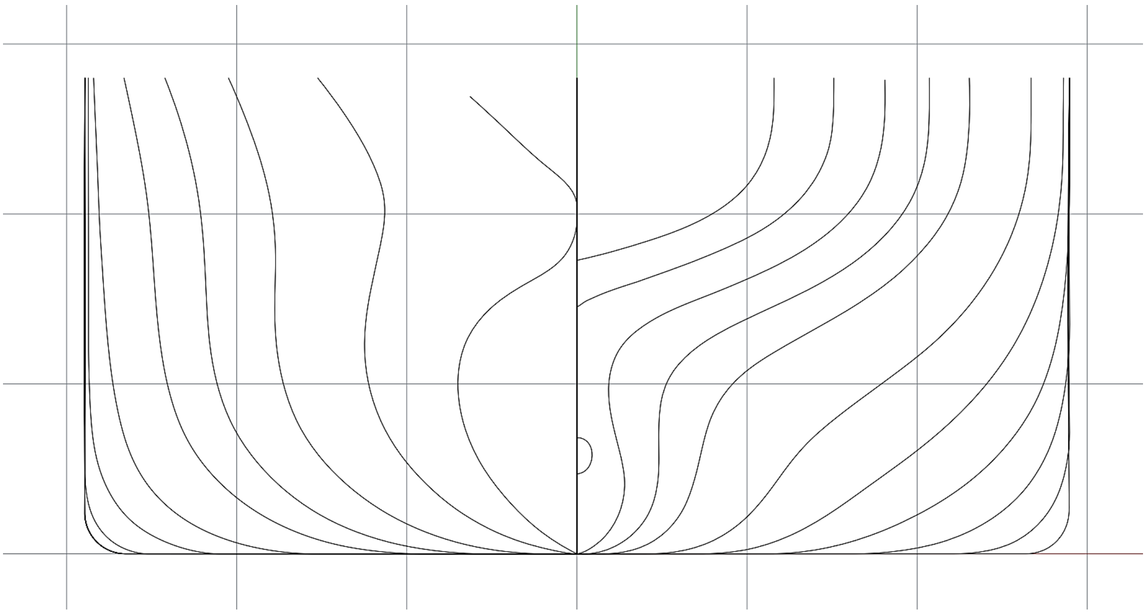


Fig 5. CAD Drawing: KRISO KVLCC2 – Body Plan Plot

4.4.2 Hydrostatics

Hydrostatics of KVLCC2 are computed for following load cases:

Trim Case	Trim	Draft Range
1	Even Keel	2 to 24 m in steps of 2 m
2	0.2 degrees (1.12 m trim by stern)	2 to 24 m in steps of 2 m
3	0.4 degrees (2.24 m trim by stern)	2 to 24 m in steps of 2 m

4.4.2.1 Even Keel Hydrostatics

Table 4: Hydrostatic Analysis Results from Python Script

Draft MS	Trim	Draft AP	Draft FP	Volume	Mass	Wet Hull Ar.	LCB	TCB
m	radians	m	m	m^3	kg	m^2	m	m
2.00	0.00E+00	2.00	2.00	24230.00	24810000.00	14350.00	176.20	0.00
4.00	0.00E+00	4.00	4.00	51590.00	52830000.00	15960.00	176.30	0.00
6.00	0.00E+00	6.00	6.00	80110.00	82030000.00	17370.00	176.20	0.00
8.00	0.00E+00	8.00	8.00	109300.00	112000000.00	18740.00	176.00	0.00
10.00	0.00E+00	10.00	10.00	139200.00	142500000.00	20060.00	175.60	0.00
12.00	0.00E+00	12.00	12.00	169600.00	173700000.00	21410.00	175.10	0.00
14.00	0.00E+00	14.00	14.00	200600.00	205400000.00	22780.00	174.40	0.00
16.00	0.00E+00	16.00	16.00	232200.00	237800000.00	24230.00	173.50	0.00
18.00	0.00E+00	18.00	18.00	264500.00	270900000.00	25670.00	172.40	0.00
20.00	0.00E+00	20.00	20.00	297400.00	304500000.00	27070.00	171.30	0.00
22.00	0.00E+00	22.00	22.00	330700.00	338600000.00	28410.00	170.20	0.00
24.00	0.00E+00	24.00	24.00	364200.00	373000000.00	29710.00	169.30	0.00
2.00	3.49E-03	2.56	1.44	23530.00	24090000.00	14290.00	166.40	0.00
4.00	3.49E-03	4.56	3.44	50810.00	52030000.00	15940.00	171.10	0.00
6.00	3.49E-03	6.56	5.44	79340.00	81240000.00	17370.00	172.60	0.00
8.00	3.49E-03	8.56	7.44	108600.00	111200000.00	18730.00	173.20	0.00
10.00	3.49E-03	10.56	9.44	138500.00	141800000.00	20070.00	173.30	0.00
12.00	3.49E-03	12.56	11.44	169000.00	173000000.00	21420.00	173.20	0.00
14.00	3.49E-03	14.56	13.44	200100.00	204900000.00	22800.00	172.70	0.00
16.00	3.49E-03	16.56	15.44	231900.00	237500000.00	24270.00	171.90	0.00
18.00	3.49E-03	18.56	17.44	264400.00	270700000.00	25700.00	170.90	0.00
20.00	3.49E-03	20.56	19.44	297300.00	304500000.00	27080.00	169.90	0.00
22.00	3.49E-03	22.56	21.44	330600.00	338600000.00	28410.00	169.00	0.00
24.00	3.49E-03	24.56	23.44	364200.00	372900000.00	29710.00	168.20	0.00
2.00	6.98E-03	3.12	0.88	22920.00	23470000.00	14200.00	156.20	0.00
4.00	6.98E-03	5.12	2.88	50080.00	51280000.00	15930.00	165.70	0.00
6.00	6.98E-03	7.12	4.88	78580.00	80470000.00	17370.00	168.90	0.00
8.00	6.98E-03	9.12	6.88	107800.00	110400000.00	18730.00	170.40	0.00
10.00	6.98E-03	11.12	8.88	137800.00	141100000.00	20070.00	171.00	0.00
12.00	6.98E-03	13.12	10.88	168400.00	172400000.00	21440.00	171.20	0.00
14.00	6.98E-03	15.12	12.88	199600.00	204400000.00	22850.00	170.90	0.00
16.00	6.98E-03	17.12	14.88	231600.00	237200000.00	24310.00	170.30	0.00

18.00	6.98E-03	19.12	16.88	264200.00	270600000.00	25730.00	169.40	0.00
20.00	6.98E-03	21.12	18.88	297300.00	304400000.00	27100.00	168.50	0.00
22.00	6.98E-03	23.12	20.88	330600.00	338600000.00	28410.00	167.70	0.00
24.00	6.98E-03	25.12	22.88	364200.00	372900000.00	29700.00	167.00	0.00

Draft MS	VCB	WPA	LCF	BM_L	BM_T	KM_L	KM_T	TPC	MCT
m	m	m^2	m	m	m	m	m	ton	ton -m
2.00	1.07	12850.00	176.80	2664.00	112.50	2665.00	113.60	131.60	2016000.00
4.00	2.09	13680.00	176.80	1416.00	59.64	1418.00	61.73	140.10	2281000.00
6.00	3.12	14110.00	176.60	985.00	40.21	988.20	43.33	144.40	2464000.00
8.00	4.16	14330.00	175.10	758.00	29.99	762.20	34.15	146.80	2587000.00
10.00	5.20	14650.00	174.10	628.90	24.47	634.10	29.67	150.10	2733000.00
12.00	6.24	14910.00	171.90	540.70	20.56	546.90	26.81	152.70	2863000.00
14.00	7.29	15200.00	169.20	484.00	17.74	491.20	25.03	155.70	3031000.00
16.00	8.34	15530.00	166.00	445.10	15.71	453.40	24.05	159.00	3227000.00
18.00	9.40	15790.00	163.00	411.30	14.00	420.70	23.40	161.70	3397000.00
20.00	10.46	16090.00	161.50	384.50	12.81	395.00	23.27	164.70	3570000.00
22.00	11.52	16270.00	160.40	355.60	11.76	367.10	23.28	166.70	3671000.00
24.00	12.58	16340.00	160.30	327.00	10.71	339.60	23.29	167.30	3718000.00
2.00	1.05	12740.00	174.80	2715.00	112.90	2716.00	114.00	130.50	1994000.00
4.00	2.07	13720.00	176.20	1450.00	60.84	1452.00	62.92	140.50	2300000.00
6.00	3.10	14170.00	175.60	1004.00	40.96	1007.00	44.07	145.10	2486000.00
8.00	4.14	14360.00	174.80	768.30	30.21	772.40	34.36	147.00	2604000.00
10.00	5.18	14700.00	173.70	638.00	24.67	643.20	29.85	150.50	2758000.00
12.00	6.22	14950.00	171.60	547.40	20.66	553.60	26.89	153.10	2888000.00
14.00	7.27	15230.00	169.00	488.20	17.80	495.50	25.07	155.90	3050000.00
16.00	8.33	15600.00	165.30	453.10	15.75	461.40	24.09	159.80	3280000.00
18.00	9.40	15870.00	162.30	416.90	14.12	426.30	23.51	162.50	3440000.00
20.00	10.46	16170.00	160.90	389.00	12.94	399.50	23.40	165.50	3611000.00
22.00	11.52	16290.00	160.20	356.60	11.77	368.20	23.29	166.80	3681000.00
24.00	12.58	16360.00	160.10	328.30	10.72	340.90	23.30	167.50	3733000.00
2.00	1.08	12630.00	172.70	2710.00	114.80	2711.00	115.90	129.30	1939000.00
4.00	2.07	13690.00	174.80	1464.00	61.33	1466.00	63.40	140.20	2288000.00
6.00	3.10	14110.00	175.20	998.10	41.23	1001.00	44.32	144.50	2449000.00
8.00	4.13	14370.00	174.30	774.50	30.42	778.60	34.55	147.10	2607000.00
10.00	5.17	14670.00	172.70	639.00	24.61	644.20	29.78	150.20	2749000.00
12.00	6.22	15040.00	170.80	559.70	20.85	565.90	27.06	154.00	2942000.00
14.00	7.27	15340.00	168.00	500.40	17.97	507.70	25.23	157.10	3119000.00
16.00	8.33	15670.00	164.80	459.80	15.82	468.10	24.15	160.50	3324000.00
18.00	9.40	15940.00	161.80	422.60	14.19	432.00	23.59	163.20	3486000.00
20.00	10.47	16190.00	160.70	391.10	12.95	401.60	23.42	165.80	3630000.00
22.00	11.53	16290.00	160.20	356.70	11.77	368.20	23.30	166.80	3681000.00
24.00	12.58	16360.00	160.00	327.90	10.72	340.50	23.30	167.50	3729000.00

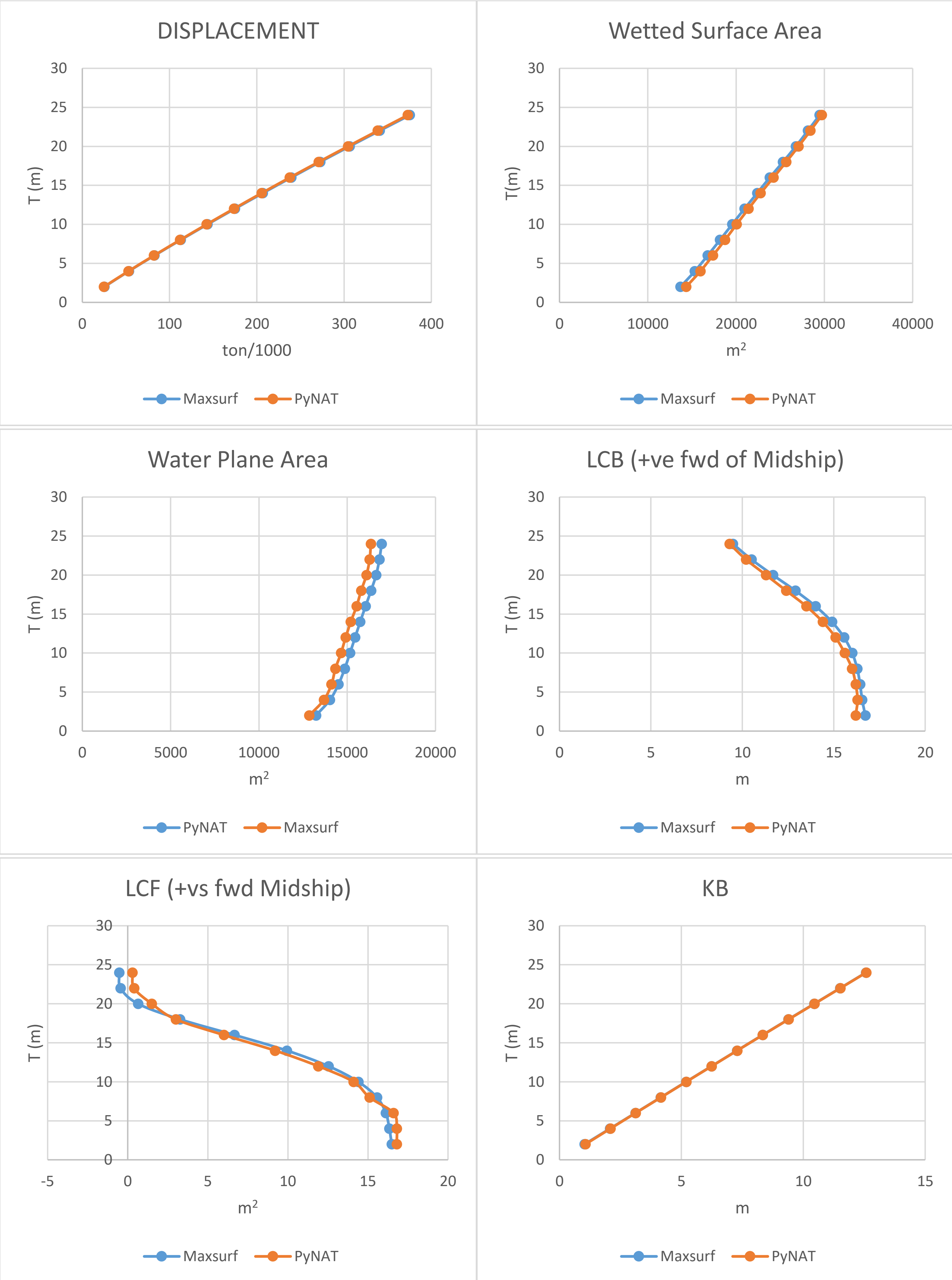


Fig 6: Variation of Hydrostatic properties along the depth for a KRISO KVLCC- 2 hull at Even Keel

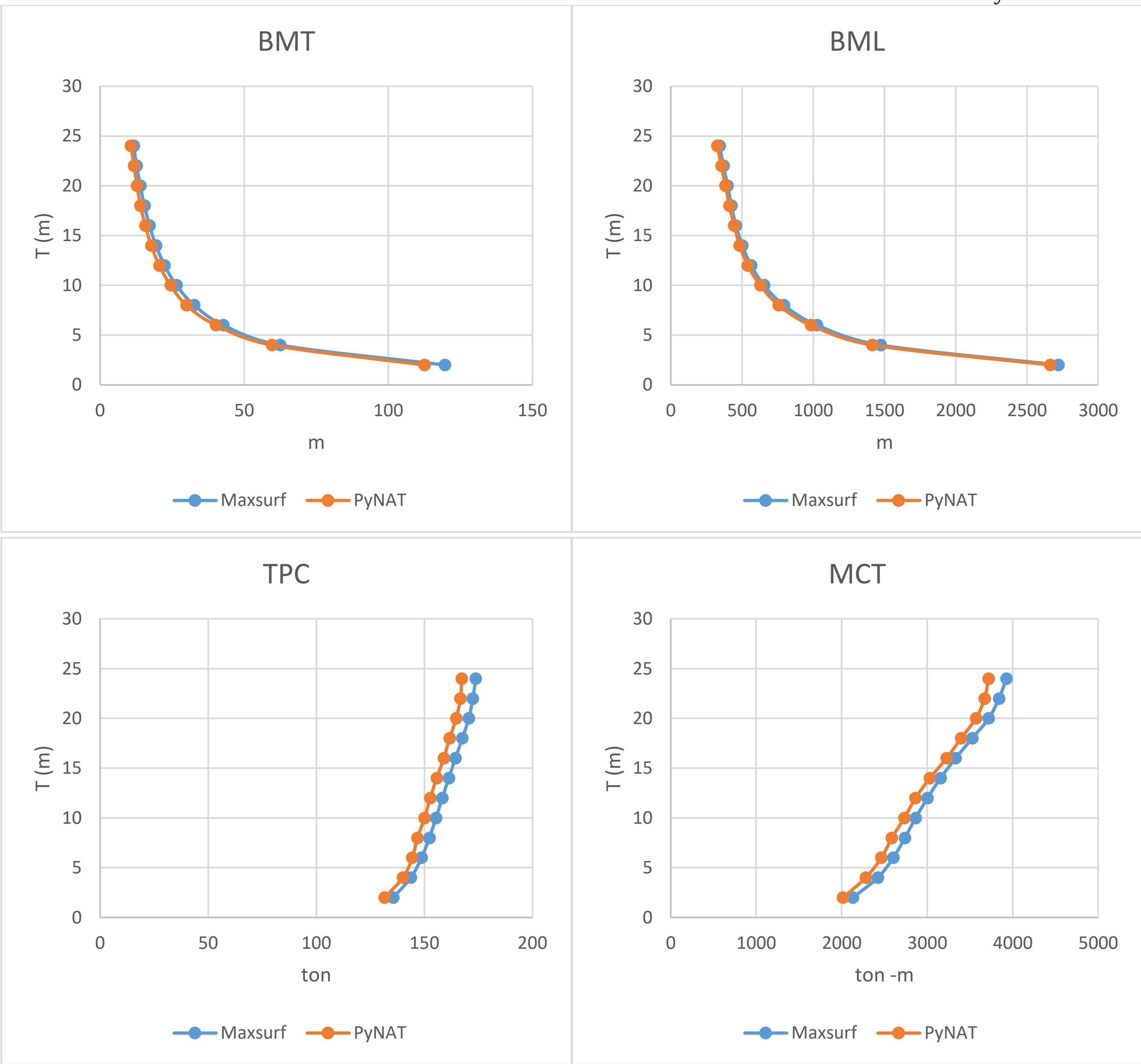


Fig 7: Variation of Hydrostatic properties along the depth for a KRISO KVLCC- 2 hull at Even Keel

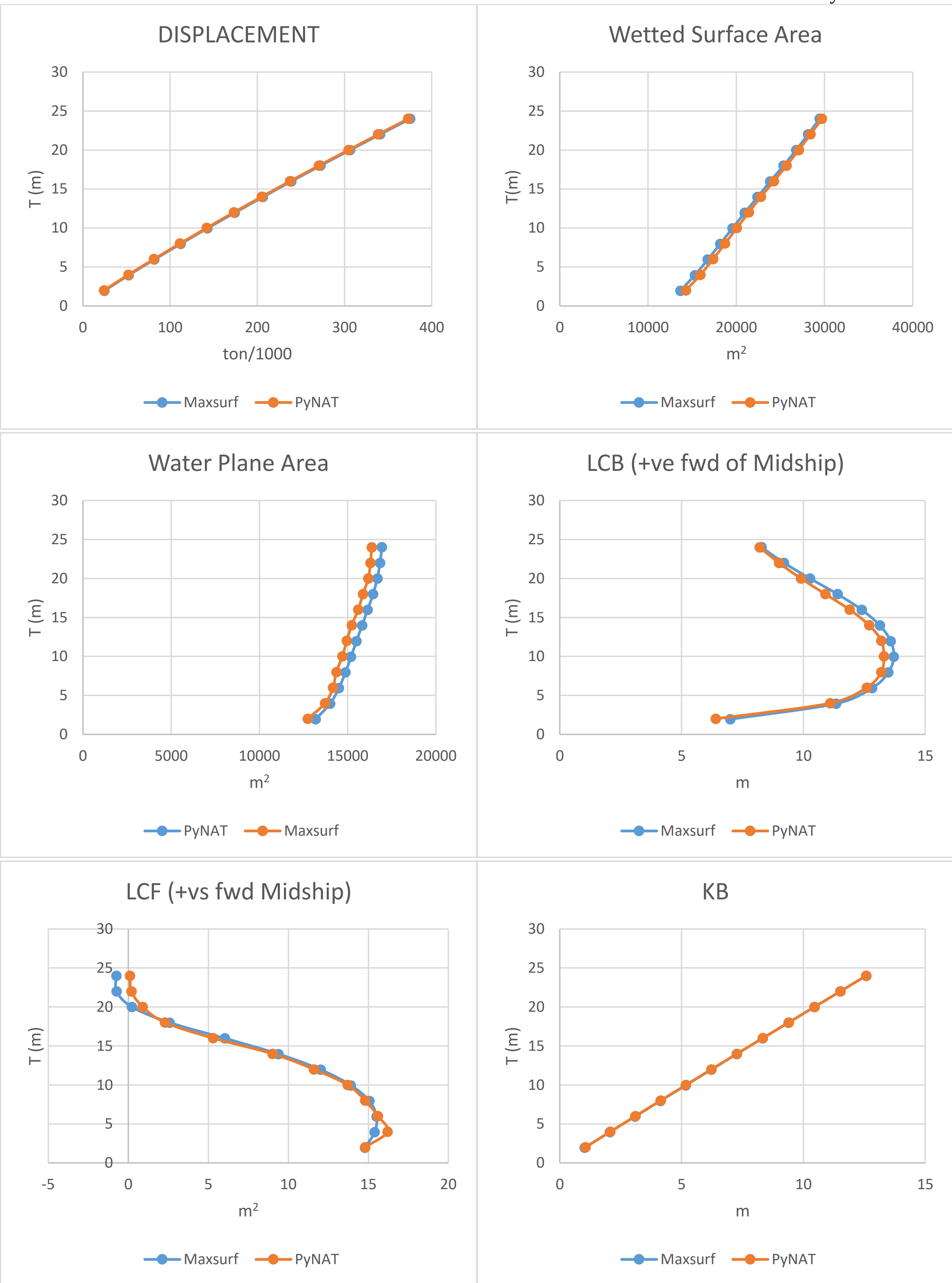


Fig 8: Variation of Hydrostatic properties along the depth for a KRISO KVLCC- 2 hull at Trim = 1.12 m (by stern)

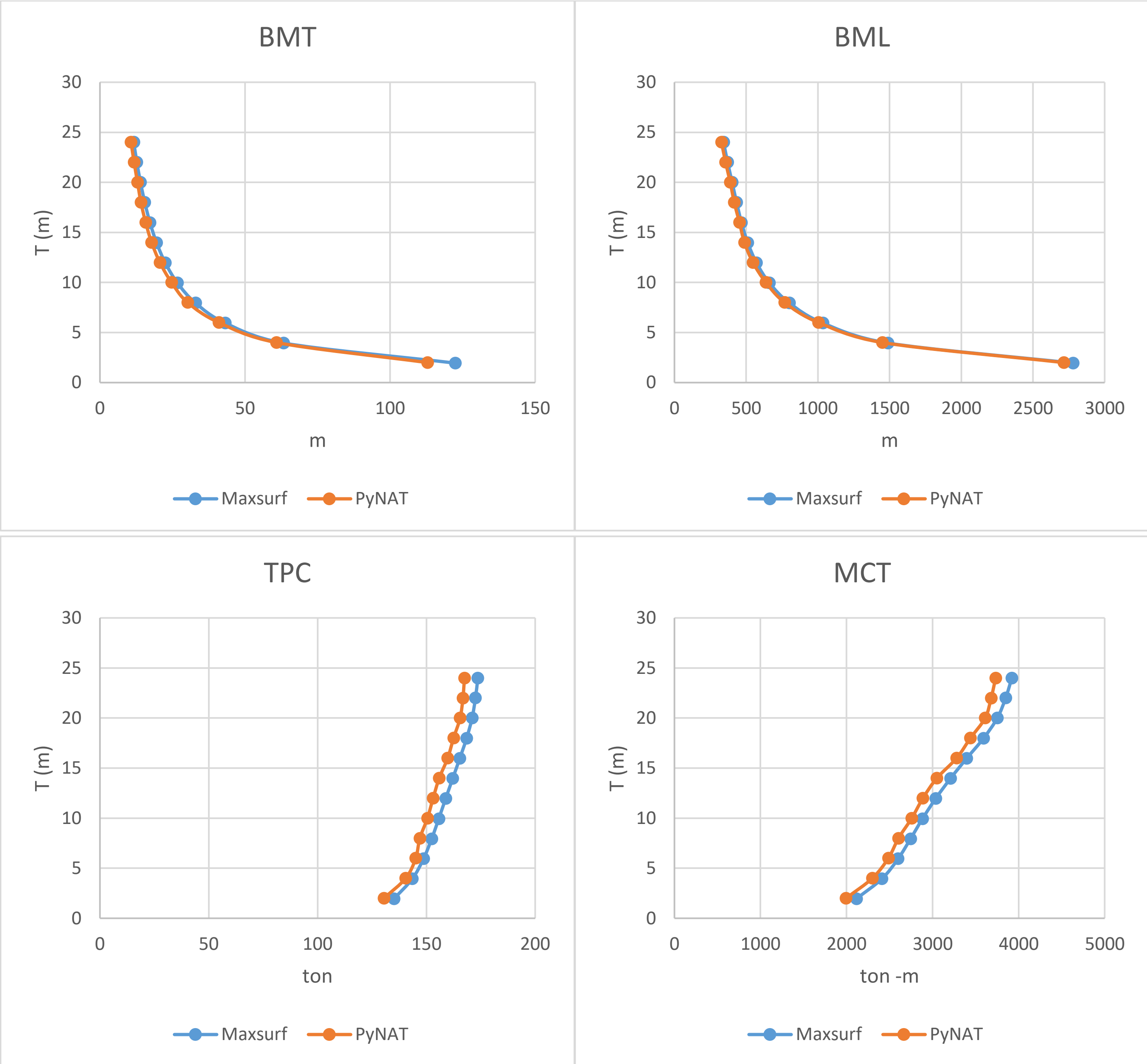


Fig 9: Variation of Hydrostatic properties along the depth for a KRISO KVLCC- 2 hull at Trim = 1.12 m (by stern)

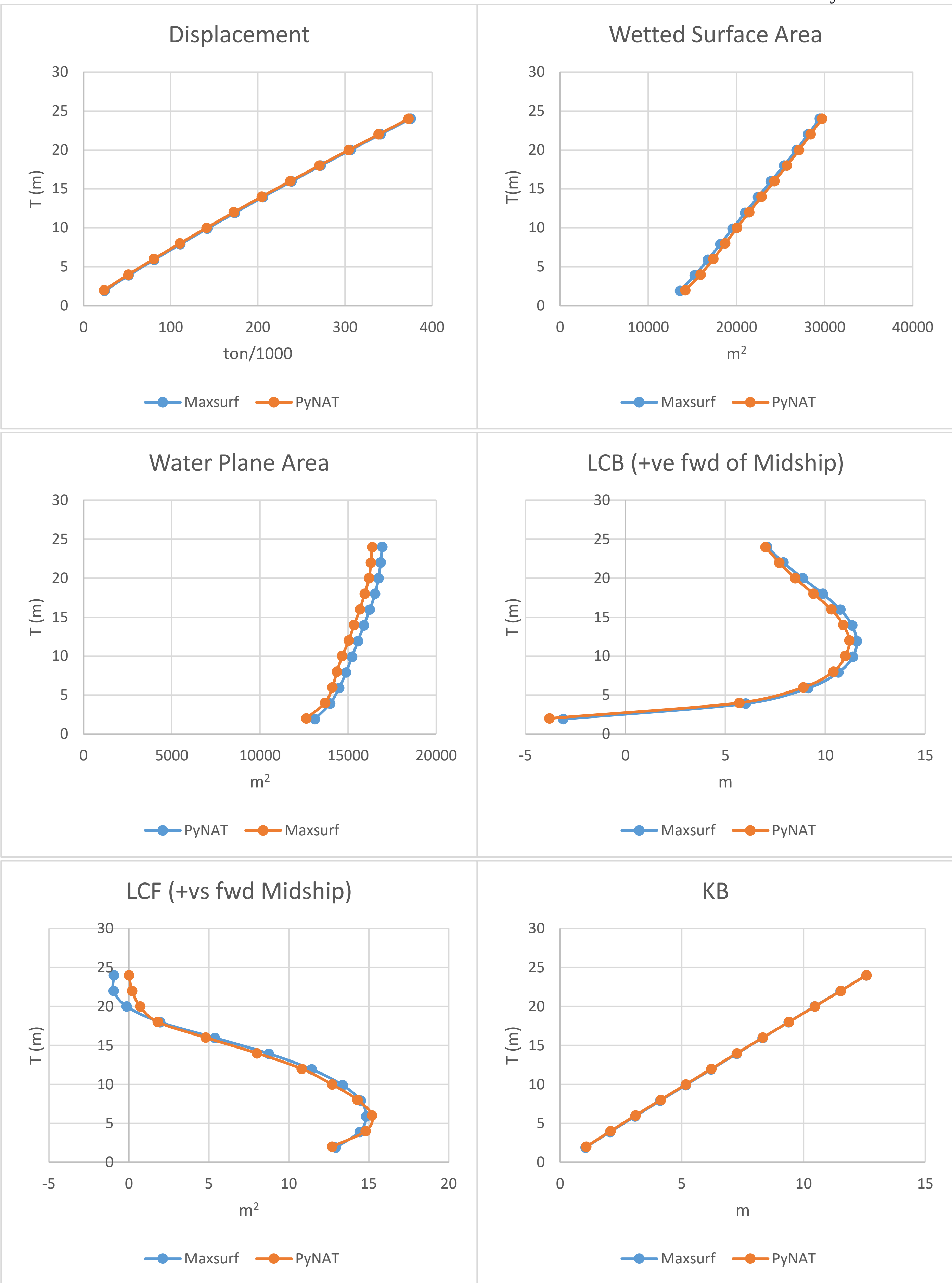


Fig 10: Variation of Hydrostatic properties along the depth for a KRISO KVLCC- 2 hull at Trim = 2.24 m (by stern)

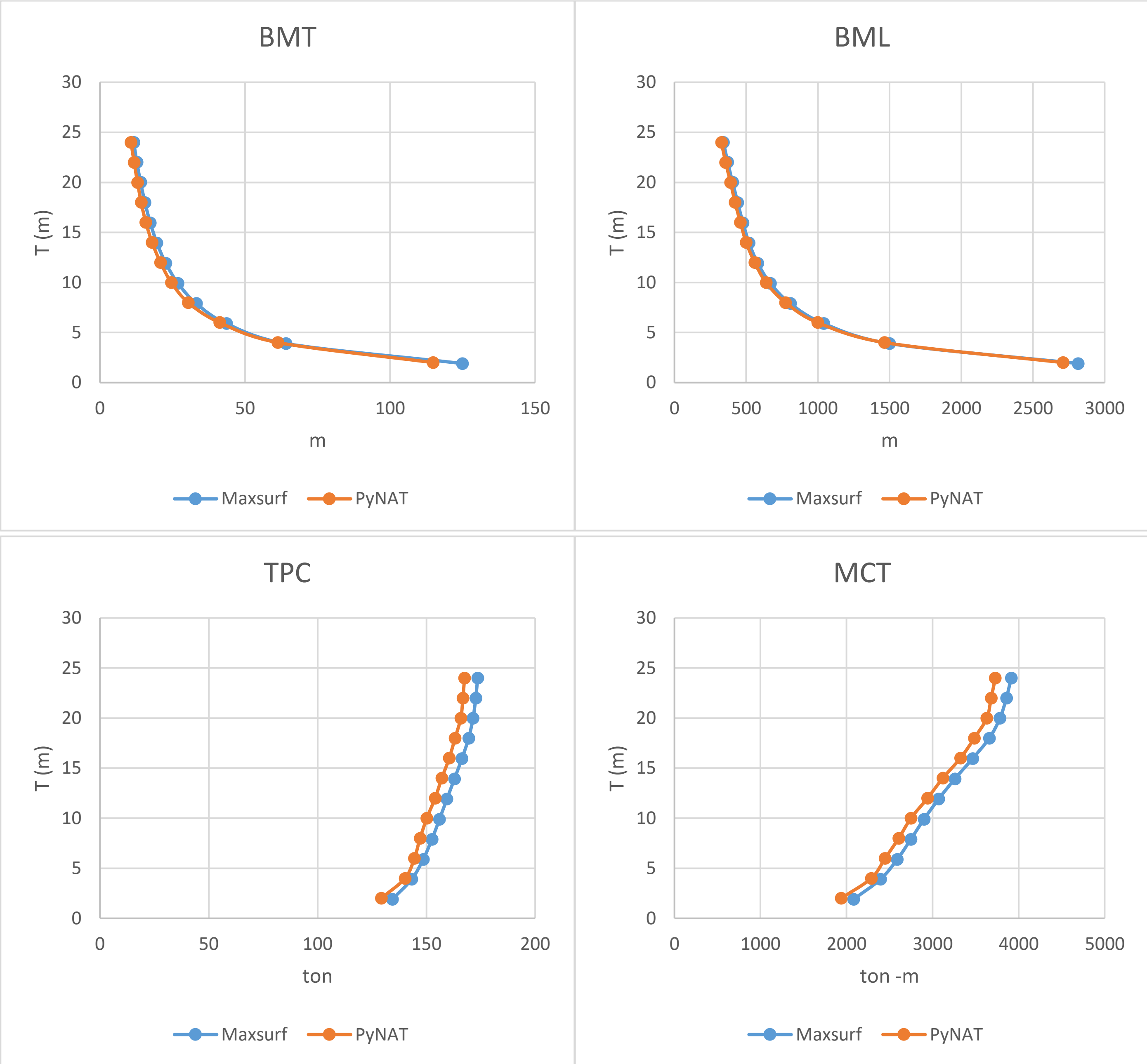


Fig 11 : Variation of Hydrostatic properties along the depth for a KRISO KVLCC- 2 hull at Trim = 2.24 m (by stern)

4.4.3 KN Curves

Table 5: KN Curve Data from Python script

Heel	Mass	KN
deg	ton	m
0	16860	0.00
0	51670	0.00
0	88560	0.00
0	126500	0.00
0	165500	0.00
0	205400	0.00
0	246300	0.00
0	288300	0.00
0	331100	0.00
0	374400	0.00
0	418000	0.00
5	2665	20.72
5	28910	9.04
5	70320	4.52
5	114400	3.17
5	159800	2.61
5	206600	2.33
5	254800	2.20
5	304300	2.14
5	354700	2.12
5	405400	2.11
5	437100	1.48
10	1807	23.67
10	18400	16.65
10	54900	10.48
10	103500	6.81
10	155200	5.31
10	208900	4.66
10	264400	4.37
10	321500	4.26
10	378100	4.13
10	418900	3.40
10	438600	2.68
15	1680	24.38
15	15340	19.61
15	46680	14.62
15	93940	10.70
15	151000	8.14
15	211700	7.00
15	274700	6.53
15	338100	6.27
15	389200	5.49

Heel	Mass	KN
deg	ton	m
30	1655	23.60
30	13770	21.58
30	40880	19.44
30	85740	17.24
30	147000	15.46
30	220200	13.84
30	291600	11.83
30	351100	10.14
30	395900	8.84
30	425300	7.92
30	439300	7.42
35	1727	22.78
35	14130	21.39
35	41780	19.93
35	87520	18.40
35	151000	17.09
35	221800	15.32
35	290600	13.12
35	350200	11.21
35	395400	9.85
35	425100	8.95
35	439300	8.49
40	1835	21.77
40	14790	21.00
40	43520	20.20
40	90950	19.32
40	155300	18.22
40	222900	16.36
40	288500	14.23
40	348000	12.21
40	394200	10.80
40	424600	9.93
40	439200	9.50
45	1977	20.59
45	15740	20.45
45	46130	20.32
45	96130	20.11
45	158900	18.90
45	223700	17.07
45	286400	15.09
45	344700	13.14
45	392200	11.68

Heel	Mass	KN
deg	ton	m
60	2652	16.37
60	20980	18.57
60	60680	20.59
60	111300	20.38
60	167000	19.18
60	224600	17.79
60	280300	16.43
60	333100	15.11
60	381700	13.88
60	419500	13.03
60	438600	12.75
65	2856	14.85
65	23700	18.14
65	65710	20.28
65	114800	19.90
65	168400	18.86
65	224000	17.67
65	277900	16.52
65	329200	15.43
65	376800	14.40
65	416900	13.59
65	438300	13.33
70	3217	13.42
70	27910	18.12
70	70570	19.64
70	118100	19.21
70	169800	18.35
70	223400	17.37
70	275700	16.45
70	325500	15.58
70	371900	14.77
70	413000	14.06
70	437800	13.81
75	3874	12.28
75	33440	18.10
75	75230	18.75
75	121200	18.35
75	171100	17.68
75	222800	16.91
75	273500	16.21
75	321900	15.57
75	367100	14.98

15	422900	4.55
15	439100	3.91
20	1660	24.45
20	14240	20.90
20	42870	17.04
20	88350	13.66
20	147300	11.00
20	214600	9.37
20	284900	8.65
20	346800	7.75
20	393800	6.66
20	424600	5.69
20	439300	5.11
25	1625	24.18
25	13740	21.47
25	41060	18.55
25	85800	15.73
25	145500	13.49
25	217600	11.77
25	290100	10.37
25	350300	9.00
25	395500	7.77
25	425200	6.82
25	439300	6.29

45	423800	10.83
45	439200	10.44
50	2161	19.27
50	17020	19.82
50	49840	20.39
50	101700	20.57
50	162000	19.25
50	224200	17.52
50	284300	15.73
50	340800	13.96
50	389600	12.49
50	422800	11.65
50	439000	11.30
55	2401	17.86
55	18750	19.16
55	54830	20.50
55	106900	20.63
55	164800	19.32
55	224600	17.75
55	282300	16.17
55	336900	14.62
55	386100	13.22
55	421400	12.39
55	438900	12.07

75	408000	14.43
75	437000	14.18

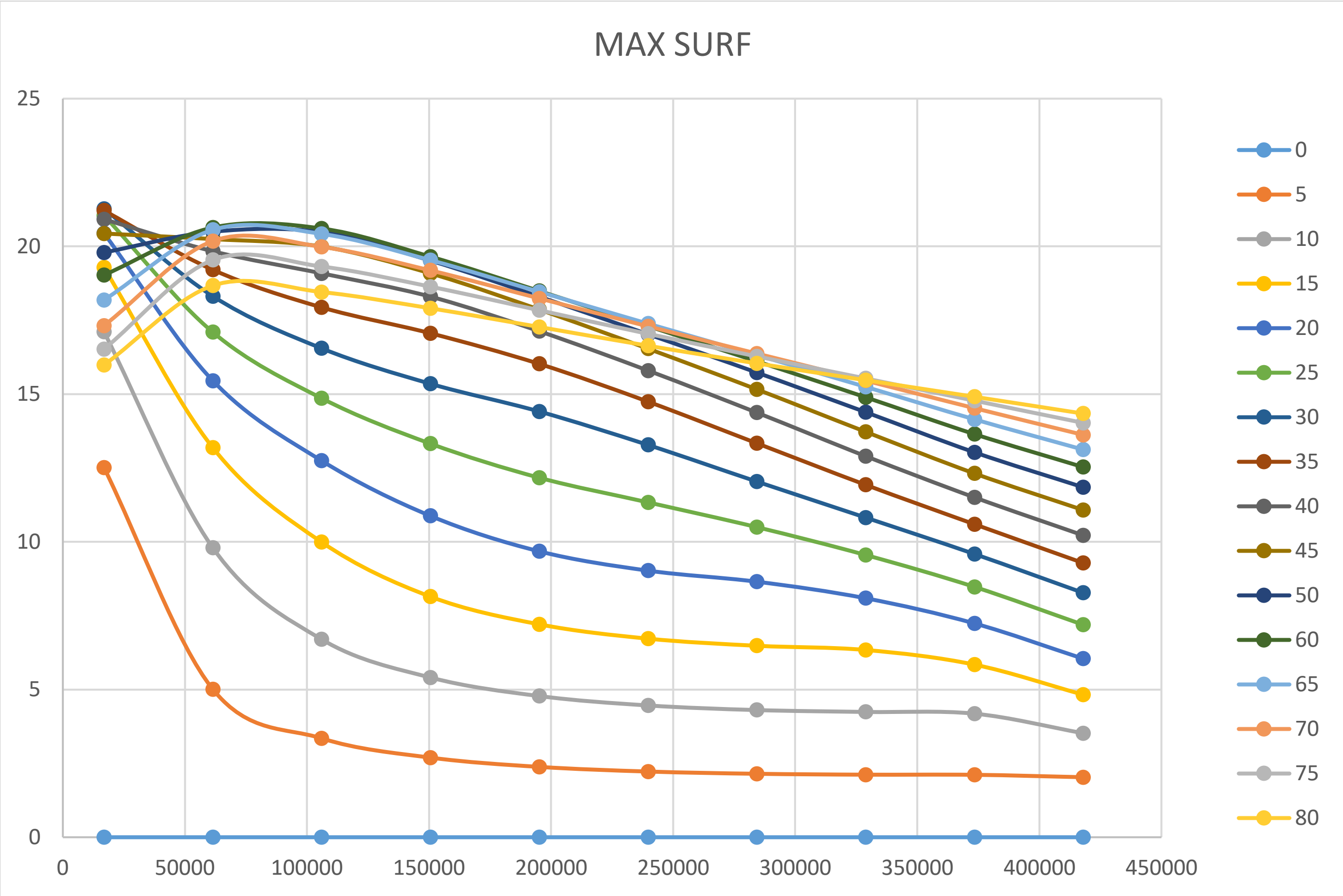


Fig 12: KN Curve of KRISO KVLCC 2 Hull form obtained from Maxsurf

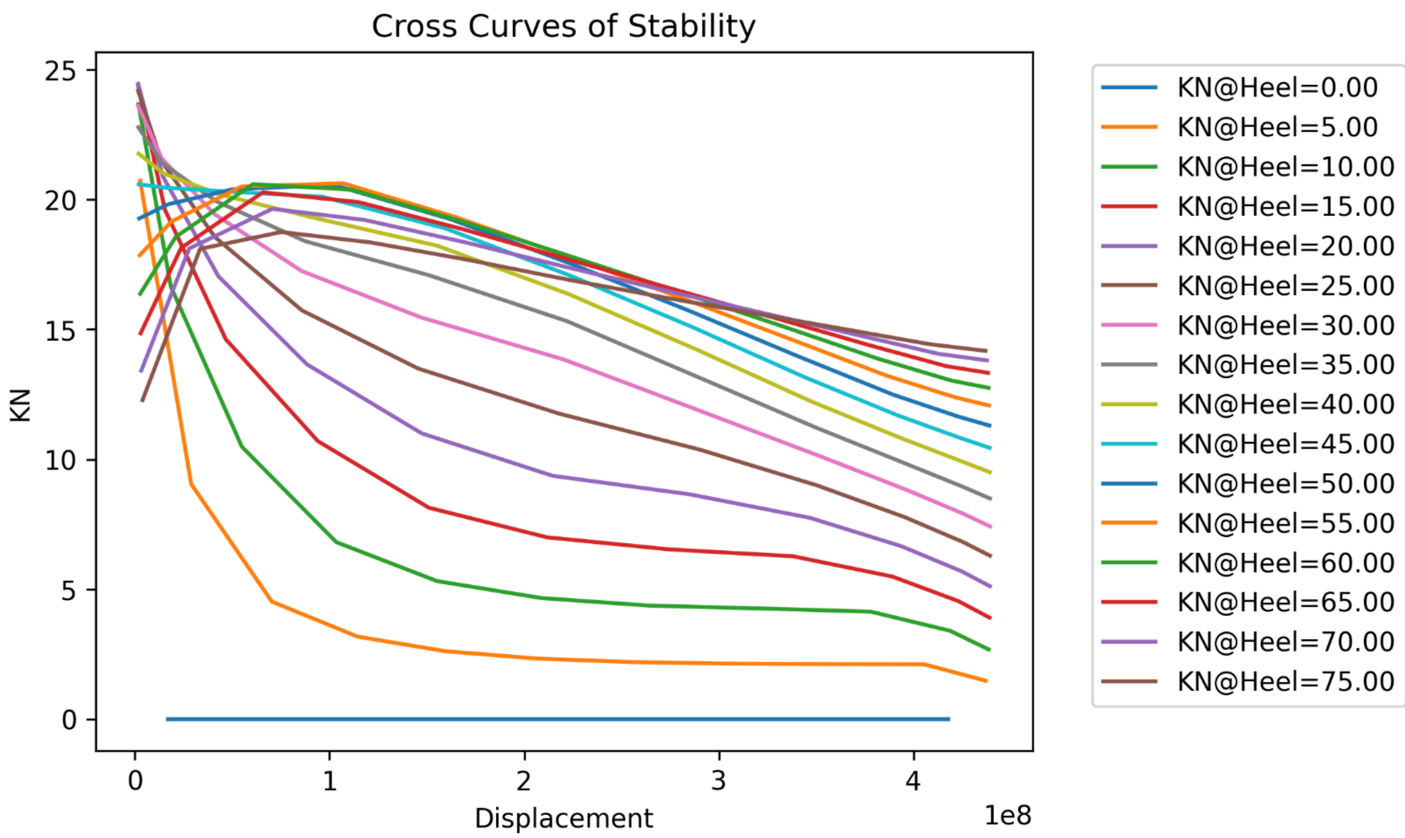
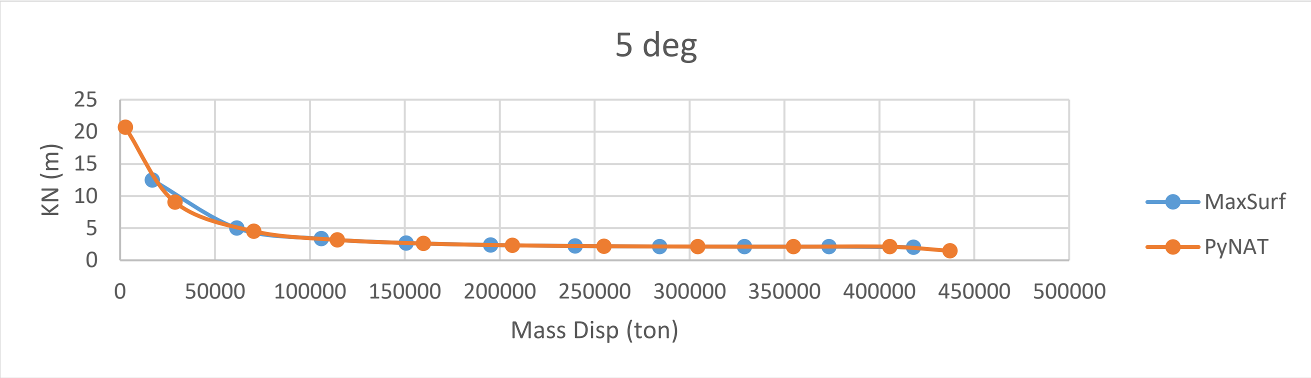
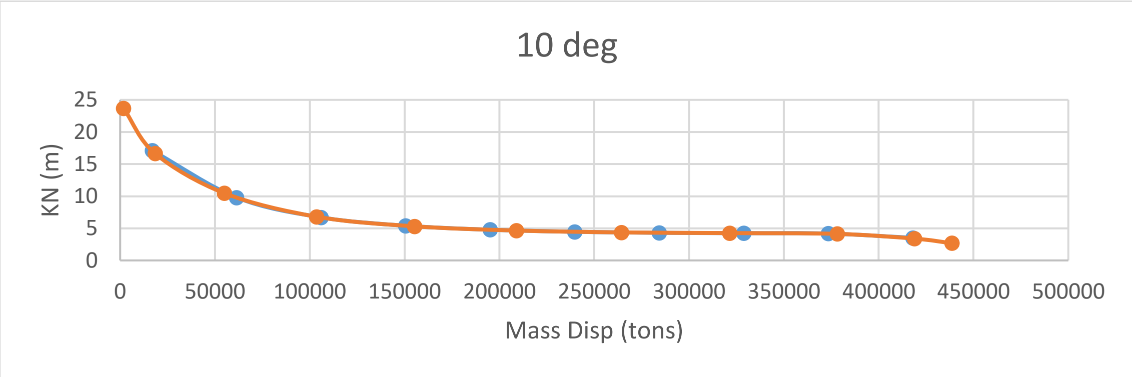


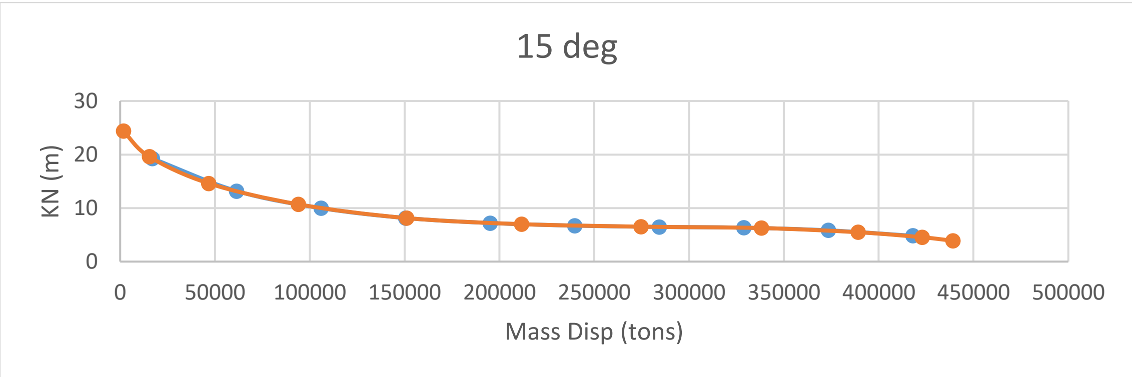
Fig 13: KN Curve of KRISO KVLCC 2 Hull form obtained from Python Script



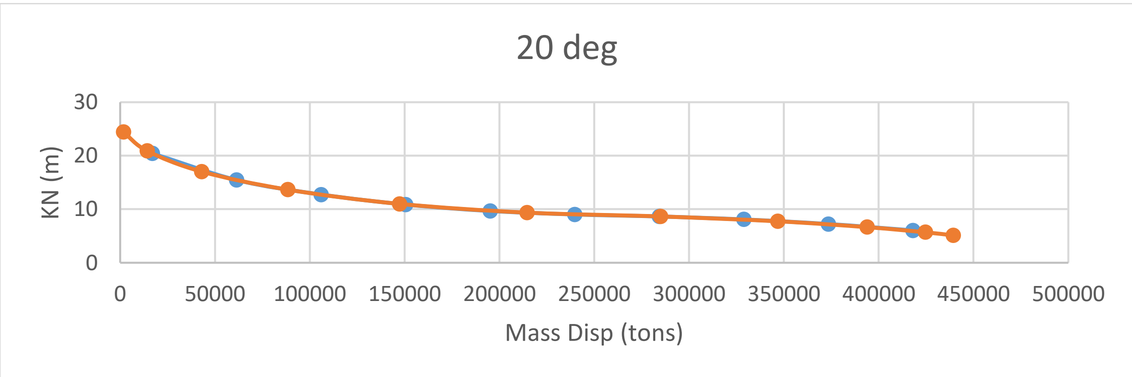
14(a)



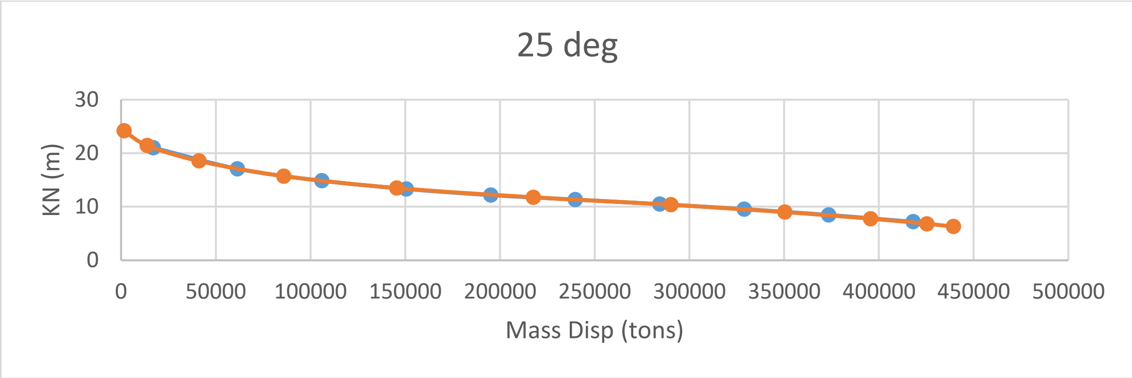
14(b)



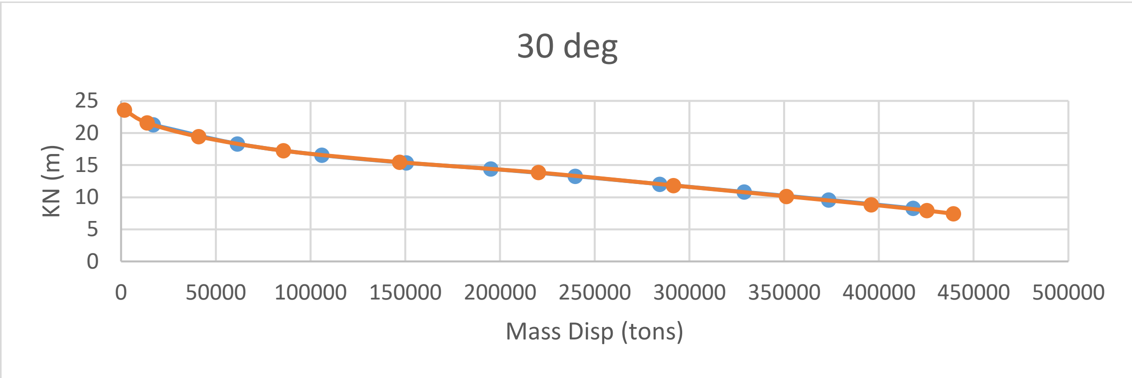
14(c)



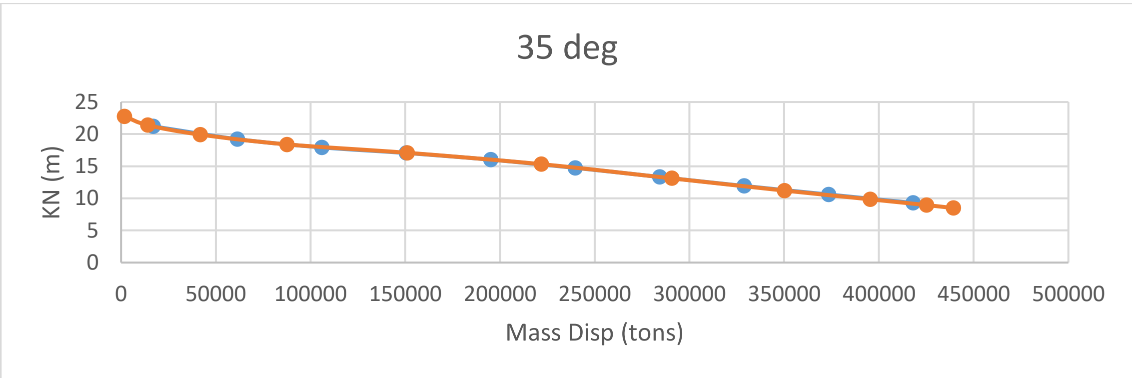
14(d)



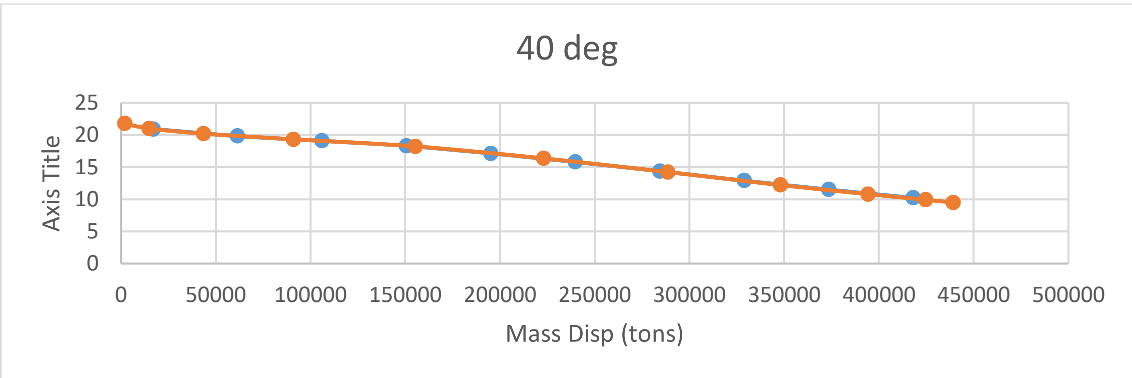
14(e)



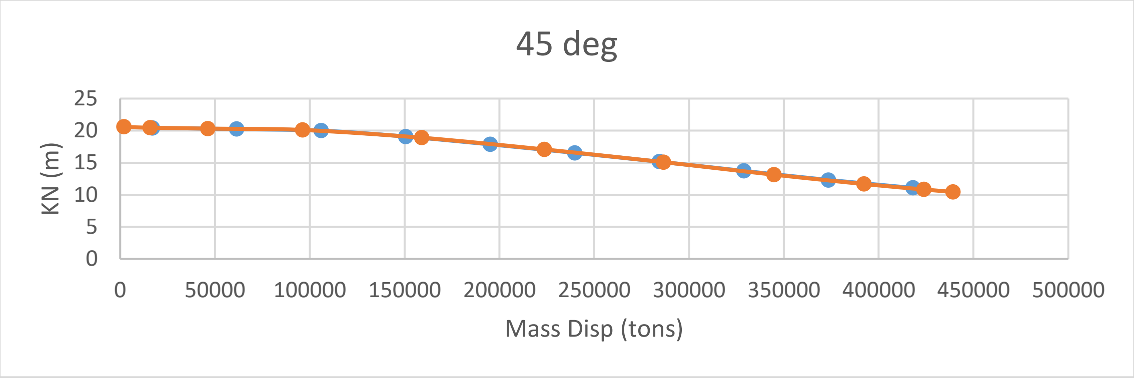
14(f)



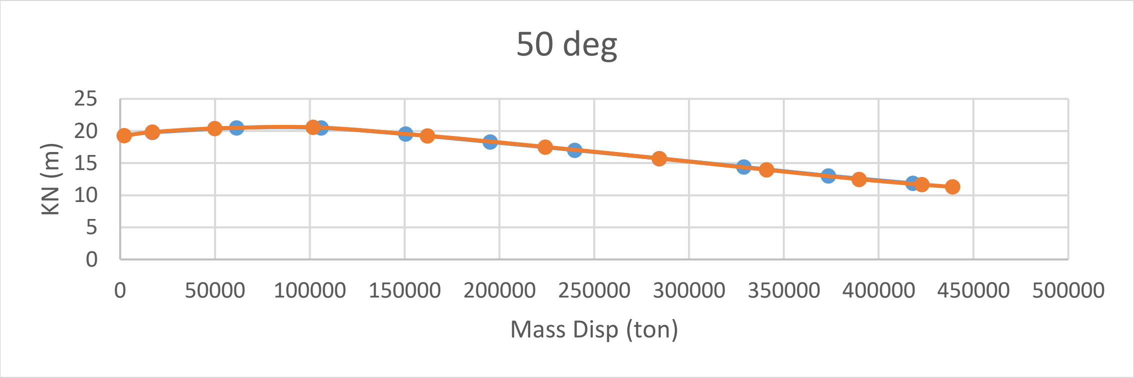
14(g)



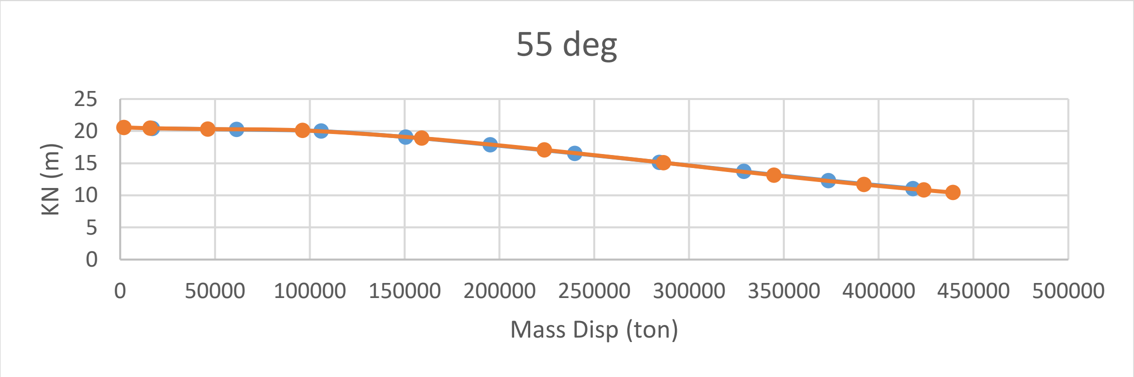
14(h)



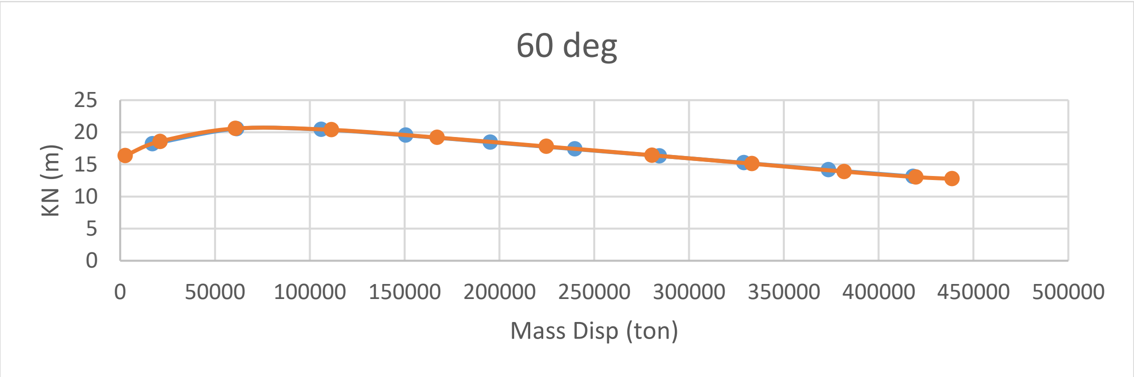
14(i)



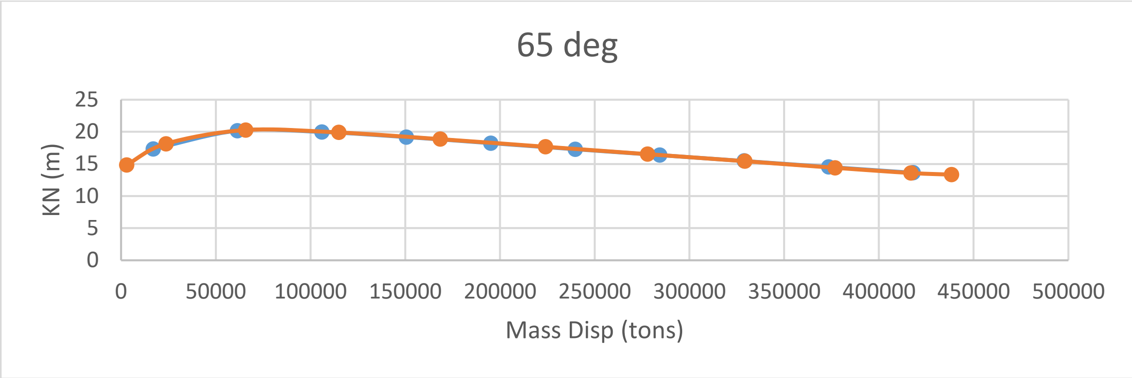
14(j)



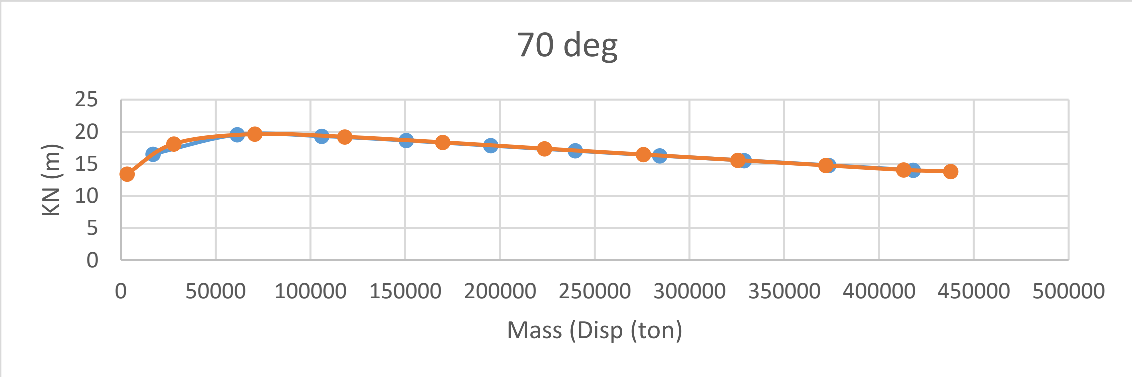
14(k)



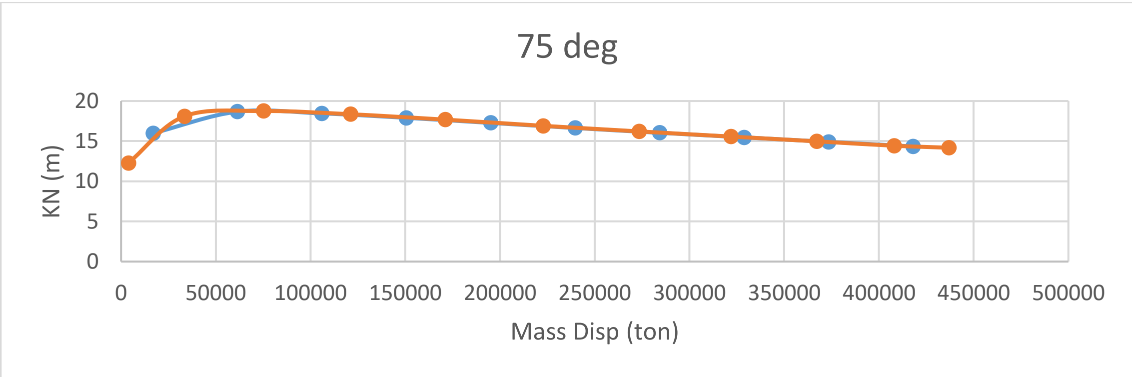
14(l)



14(m)



14(n)



14(o)

Fig 14(a) –14(o): Comparison of KN curves from Python Script with that of Maxsurf

(Blue Line → Maxsurf Results, Red line PyNAT results)

5 Large Angle Stability

Table 6: The GZ curve data from python script

Heel	GZ
deg	m
0.00	0.00
5.00	0.64
10.00	1.31
15.00	2.02
20.00	2.51
25.00	2.72
30.00	2.75
35.00	2.67
40.00	2.50
45.00	2.21
50.00	1.85
55.00	1.41
60.00	0.92
65.00	0.39
70.00	-0.16
75.00	-0.72

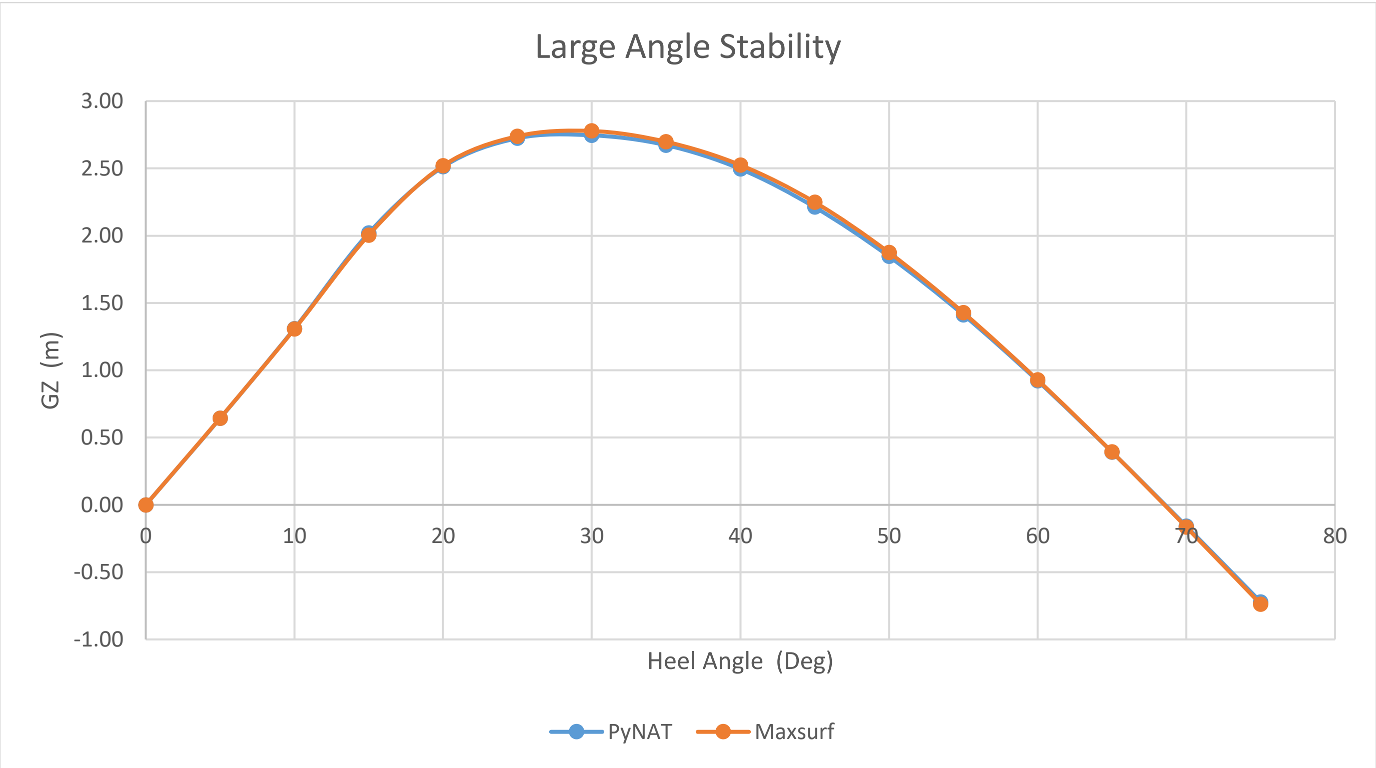


Fig 15: The GZ curve for KRISO KVLCC2 at Loading condition defined by Mass Displacement=312000000 tons and VCG (KG) = 17 m

6 Conclusion:

- A python script is developed to perform hydrostatic and stability analysis on a hull form defined by offsets.
- The results are compared with a commercial software (Maxsurf) and found to be reasonably accurate.
- Minor variations in hydrostatic properties is attributed to the variation of hull grid density used for the Python Script and Maxsurf.

7 References:

- Edward. V. Lewis (1967) Principles of Naval Architecture, SNAME
- E. C. Tupper and KJ Rawson (2001), Basic Ship Theory I & II, Butterworth-Heinemann
- Python 3.9.5 Documentation, online resource.
- Numpy User Guide, Release 1.20.0 (2021)
- SciPy Reference Guide, Release 1.6.0 (2020)