Parametric Modelling of Hulls for Small Craft

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Abstract. The objective of this work is to develop three parametric models, each one corresponding to a different type of yacht hull. More specifically, the models elaborated concern a planning hull of a motor yacht, a displacement hull of a motor yacht and a displacement hull of a sailing yacht. First, each kind of vessel has been studied, understanding the different characteristics that govern their construction. They have been discomposed to evaluate and analyse the "Isocurves" that permit the 3D modelling of the three hulls; in this way, different kinds of curves and control points have been found, which permit to modify the surface's shape according to the will of the final user. Using Rhinoceros 3D (www.rhino3d.com), different ways to obtain a surface from these curves have been analysed, while the best one has been chosen, intended as the one which better represents such surfaces. Further, the dimensions and the admitted values of the geometries have been studied, evaluating their main parameters, such as angles, lengths, or tangents.

After the part of the study of forms, the practical work has started, by developing the code that allows creating the parametric model into the Rhinoceros 3D system. The program used to generate the final shapes is Grasshopper (www.grasshopper3d.com), a visual programming software integrated in Rhinoceros 3D in the form of a plug-in. It is possible to generate a code by defining a cause-effect system, led by using parameters as inputs, the surfaces of the hull as main core, generating both an excel file with the main dimensions and the graphic section area curve as output. Once the desired shape is obtained, the hulls got compared with existing vessel models to further validate the final surfaces' accuracy. Moreover, the code has been implemented with the addition of new calculations, such as the Lines Plan, the Offset Table, and the main dimensions of the model, in detail, length overall, beam, draft, block coefficient, prismatic coefficient, transversal and longitudinal metacentric and the graphic of the curve of area.

NOMENCLATURE

L_{OA}	Length Over All
L_{WL}	Length Water Line
B_{MAX}	Maximum beam of the hull
B_{WL}	Beam at the water line
T	Design draft
D	Vertical distance from the deepest point of the keel to the sheer line
FB	Freeboard, vertical distance between the sheer line and the water plane

1 INTRODUCTION

The shipbuilding world market has moved from Western Europe countries to Asia in the last century. Europe managed to keep a little slice of the business thanks to its strategic specialization as a niche player. The leisure boats market is still strong and well settled in the east of the world. A sector of the market includes the luxury yachts. North America is the biggest market for recreational boats, thanks to its developed infrastructures, extended coastline and rich population, more people participate in marine activities every year. The second biggest market is the European one. Italy, UK, France, and Germany are some of the biggest players in the recreational boats business. Parametric modelling is a method that allows to generate the hull from zero, using the main hull dimensions, form coefficients, and parameters. It is a very good mean to generate a preliminary design model in the first stage of the project.

2 LITERATURE REVIEW

Parametric modelling is a method that allows to generate the hull from zero, using the main hull dimensions, some form coefficients, and several parameters. The most developed applications about global parametrization are FORAN hull form generator (www.senermar.es/NAVAL/foran/en) and FRIENDSHIP modeler (www.friendship-systems.com). The FRIENDSHIP modeler is a parametric design software based on the use of sections to obtain the hull form. FORAN uses parameters, which contain geometric, hydrostatic, and hydrodynamic characteristics, and are connected to the formulation of the waterline. (Rodriguez and Fernandez-Jambrina, 2012). The Bezier curves are a very good mean because they permit the modification of the curve without moving the control points, but just changing the weights assigned to them (Ingrassa et al, 2021). The traditional way to model a hull is by the employ of waterlines and sections. The third group of curves that can be used by the designer are the buttocks (Mancuso, 2005). The parameters can be of two typologies: global parameters and local parameters. The global parameters are the ones that modify the general shape of the hull, for example L_{wl} or B_{wl}, and the local parameters are used to vary a specific curve or surface of the vessel, for example the value of the tangent at the bow (Sener, 2016). All the planar curves are described by the following form parameters: Position (X, Y, Z), Tangent angle, Curvature, Area, Centroid, Fairness. The form parameters describing the F-spline are the three coordinates (X, Y, Z), angle, volume, and centroid (longitudinal centre of buoyancy) (Hang et al, 2012).

3 MODELLING METHODOLOGY

The geometric reference system adopted is set with the zero at the intersection point between the vertical passing through the aftermost point of the sheer line (Daft) and the XY plane passing through the lowest point of the keel. ZZ axis is parallel to Daft and XX axis lies on the centreline plane.

3.1 DISPLACEMENT SAILING YACHT HULL

CURVES STUDY

The main lines of the sailing yacht are the sheer line, the deck line, the profile curve, the waterline and the cross section. The sheer line is usually straight, without any curvature. It can be parallel to the water plane, or inclined, with an angle with the ZZ axis with origin at the aft point of the sheer line that lies in the range of about 88° to 90°. The deck line has the angle of entrance at the bow that can have a range from 15° to 25°. The maximum beam of the sailing yachts can reach a value equal to the 16% of the Loa. The maximum beam can be forward the Lpp/2, which is a very rare case, or before it with a maximum value up to 14% of Loa. The bow contour can have a null inclination, so that this element of the hull is parallel to the Z vector, or it can assume an inclination going from 0° to 45°. The intersection point between the bow line and the waterline has two angles, one defined as the up-waterline angle (Wu) and the other defined as the down waterline angle (Wd). Wu has a range going from 17° to 74° and Wd has a range going from 11° to 67°. The keel line is the lowest curve of the hull. It is a 2D curve that lies on the centreline plane. It starts from the lowest point of the transom, and it ends at the bow line connection. Otherwise, the keel line can be partially straight and parallel to the waterplane, the straight segment length depends on the Loa of the yacht, so it can be studied as a percentage of it. The transom is made up of three curves, two straight lines and a rounded one. The range of the transom beam, corresponding to CF line, goes from 4% of Loa to 17% of Loa. The length of the CG (straight) curve goes from 4% of Loa to 11% of Loa.

MODELLING METHODOLOGY

The lines used to create the hull are sheer line, deck line, waterline, transom line, keel line, bow line and cross section. The parameters used to control the sheer line are the deck length (Ld) and three Depths, that are measured at the central point Dmid, at the most aft point Daft and at the most forward point Dfrw of the line. The deck line has two linear parameters Bmax, that is the maximum beam and XBmax that is the longitudinal position of Bmax; and two angular parameters, De entrance angle and Dr angle of run. The transom line uses parameters Tl and Tv to control the longitudinal and the vertical position of the lower point of the transom. Parameter Th controls the beam of the transom. At point F parameter Tu can be used to modify the angle included between the line FG and the XZ plane passing through F. At the lower point of the transom the angle taken in between the plane XY passing through G and the transom contour is controlled by parameter Td. The bow line has two linear parameters Bl and Bv to set the position of the lower point H and two angular parameters Bu and Bd to set the curvature of the line. The keel is built with three distinct segments. The parameter Xt controls the longitudinal distance from Daft to point L, which has two angular parameters Kla and Klf. At point I it is used the same parameters construction of point L. Point H and point G have each one an angular parameter Pb and Kt. The waterline has the entrance angle (Ewl), the angle of run (Rwl), the draft, the waterline beam Bwl, the longitudinal position of Bwl (XBwl) and Cw. The cross-section id identified by two angular parameters, Cu at the deck and Ck at the keel, plus a linear one Xc to set the X coordinate of the section. The script generates also the Lines Plan, the Offset Table, section area curve, the main coefficients (Cb, Cm, Cp), the Inertia and the metacentric radius.

VALIDATION

It is chosen a real sailing yacht hull and it is made a comparison with the model created. The real hull is the Figaro Solo of 1989 and 1992, designed by Groupe Finot and Jean Berret, constructed in the shipyard Bénéteau. The Lines Plan is studied using Rhinoceros 3D

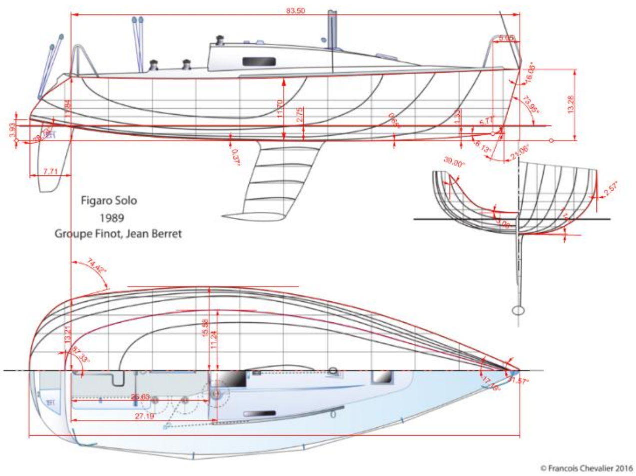

Figure 3-1: Figaro Solo forms study

All the parameters are inserted into the Grasshopper code and the output is compared.

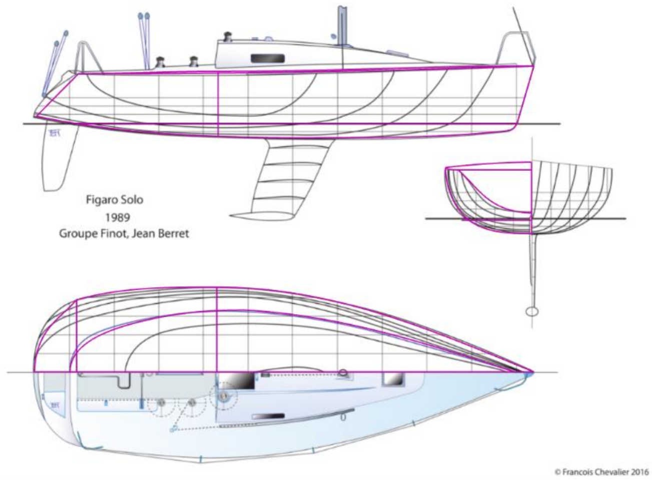

Figure 3-2: Figaro Solo Lines Plan with overlayed, in violet, the code main lines output.

The code is not able to perform a perfect reproduction of all the main lines, the transom is the curve with the less precision. The deck line is well shaped, as much as the keel line and the bow line.

Table 1: Grasshopper Offsets, using the parameters of Figaro Solo

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
WL1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WL2	0.00	0.00	0.46	0.73	0.94	1.11	1.25	1.36	1.43	1.44	1.34	1.22	1.09	0.94	0.77	0.60	0.43	0.26	0.09	0.00
WL3	0.89	1.17	1.37	1.53	1.65	1.74	1.79	1.82	1.84	1.83	1.75	1.63	1.49	1.32	1.12	0.91	0.68	0.45	0.21	0.00
WL4	0.00	1.41	1.58	1.72	1.83	1.91	1.97	2.01	2.04	2.04	1.96	1.84	1.69	1.51	1.30	1.07	0.83	0.57	0.30	0.03
WL5	0.00	1.66	1.80	1.92	2.01	2.07	2.12	2.15	2.16	2.14	2.06	1.95	1.80	1.63	1.42	1.19	0.94	0.67	0.39	0.09

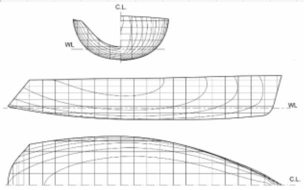

Figure 3-3 : Grasshopper lines plan using the parameters of Figaro Solo.

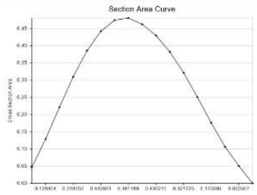

Figure 3-4: Grasshopper cross area curve using the parameters of Figaro Solo.

3.2 DISPLACEMENT MOTOR YACHT HULL

CURVES STUDY

The main lines of the displacement motor yacht are the sheer line, the deck line, the profile curve, the waterline, and the cross section. The sheer line can be straight or concave. The most forward point can have the same Z coordinate of the after most one or it can have a bigger value. The angle (St) taken between the YZ base plane, and the sheer line can vary between 82° and 94°. The angle (Sb) formed between the sheer line and the XY plane with origin at the extreme bow can reach 15°. The deck line has an entrance angle that goes from 32° to 63°. The angle of run values go from 79° to 87°. The waterline can have an entrance angle (Ew) which values go from 19° to 30° with a maximum variation in front of the entrance angle at the deck of the 64%. The bow contour has three angular parameters one at the upper point (Bu), that varies between 0° to 25° and two at the waterline intersection. The upper external angle (Bwu) goes from 40° to 73°. The lower internal angle (Bwd) goes from 37° to 70°. The keel line has the bigger number of parameters. The angle (Pb) formed at the most forward point of the curve goes from 38° to 70°. the angle (Kt) at the aftermost point of the line goes from 62°to 89°. The transom can be composed of straight or rounded segments. The surface of the transom can be parallel to the YZ plane, or it can be inclined in direction of the bow with an angle (Tb) that can reach 23°.

MODELLING METHODOLOGY

The form curves used to create the hull are the same of the ones used for the sailing yacht. The sheer line, the deck line, the bow line and the cross section are created with the same code, the other lines have a new script. The transom has a new parameter that is Tb, which controls the longitudinal curvature, the other parameters are Th, transom beam, Tv and Tl that define the position of the lower point. The keel line has the first and the last points that are the lower point of the bow line H and the lower point of the transom G. Two other control points L and I move along the Lwl. G and H have two angular parameters. L has one angular (Ksa) parameter and two linear ones (Xl, Zl). I has one linear (Pl) and one angular (Ksf) parameter. The waterline parameters are T, angle of run, entrance angle, Bwl and XBwl, the difference with the sailing boat is that in the motor yacht this line ends at the transom. The surface and the further calculation are elaborated with the code of the sailing yacht hull.

VALIDATION

The existing displacement motorboat chosen is the Espoir outboard designed by Uffa Fox.

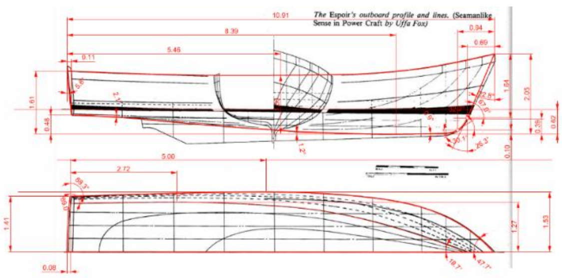

Figure 3-5: Espoir study of forms

All the parameters are inserted into the Grasshopper code and the output is compared

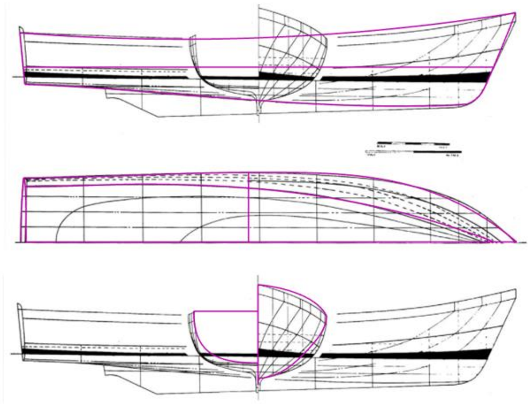

Figure 3-6: Espoir Lines Plan with overlayed the main lines output of the Grasshopper code

Not all the lines correspond to the target curves. The deck line, the keel line and the waterline have a good precision, but the transom line and the cross-section area, because of their complex shape, are two difficult geometries to elaborate.

Table 2: Offset Table generated by the Grasshopper code using the Espoir values.

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
WL1	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.44	0.51	0.54	0.49	0.43	0.38	0.32	0.25	0.18	0.11	0.05	0.00	0.00
WL2	0.00	0.88	0.90	0.93	0.95	0.97	0.98	0.98	0.97	0.94	0.87	0.81	0.73	0.64	0.54	0.42	0.30	0.16	0.03	0.00
WL3	0.00	1.25	1.26	1.28	1.29	1.30	1.29	1.28	1.25	1.21	1.16	1.10	1.02	0.92	0.81	0.67	0.51	0.33	0.12	0.00
WL4	0.00	1.37	1.39	1.40	1.42	1.43	1.44	1.44	1.44	1.42	1.39	1.34	1.28	1.20	1.10	0.96	0.78	0.56	0.29	0.00
WL5	0.00	1.41	1.42	1.44	1.46	1.48	1.50	1.51	1.52	1.52	1.51	1.49	1.46	1.41	1.32	1.19	1.01	0.78	0.47	0.08

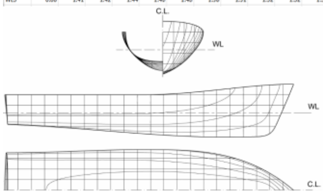

Figure 3-7: Lines plan generated by the Grasshopper code using the Espoir values

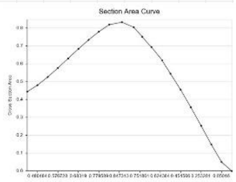

Figure 3-8: Cross section area curve created by Grasshopper code using Espoir values

3.3 PLANNING MOTOR YACHT HULL

<u>CURVES STUDY</u>

The planning hulls are the fastest of the three different typologies studied. Thanks to their shape when they gain speed part of the hull raises above the water. The hulls characterized by this property are V-shaped and have squared forms with evident angles, plane regions and convex planes. The lines needed to develop this kind of shapes are the following: sheer line, deck line, bow line, keel line, transom line and the chine line. The sheer line can assume the shapes of the previous vessels plus a new configuration. This form curve can be convex. It is obtained the range of values of the angle at the transom (St) and the one at the bow (Sb). St moves from a minimum of 83° to a maximum of 92° and Sb goes from a minimum value of 84° to a maximum of 94°. The deck line can be all rounded or it can have a straight segment and a rounded one. The angle at the stern, Ds, goes from 72° to 90°. The straight section DSS, can reach a maximum extension of 55% of the Loa. The entrance angle, Ea, can vary from 32° to 72°. The maximum beam has a range going from 13% to 26% of Loa. The chine line is a curve characteristic of the planning yachts. It is a 3D form curve. The chine divides the hull surface into two distinct surface regions, which can be concave, convex, or plane. Two angles for each surface are needed to study their shape. The bow can be designed straight or rounded. The angle at the most forward point goes from 5° to 62°. The other two angles studied to describe this design curve are the ones at the intersection point between the bow contour and the waterline. One is included between the waterline and the upper part of the bow line, Iwu, which values go from 17° to 74°, the other is taken between the waterline and the lower part of the bow line, Iwd, which range is from 15° to 63°. The keel line in most of the design studies is constructed to be almost completely straight from transom to bow. It is studied the angle at the stern, Kt, which goes from 87° to 95°. Angle Ka is the one at the connection point with the bow. Its values go from 15° to 63°. The transom can be inclined forward, or it can be perpendicular to the water plane. In case of bow way inclination, the point with the smallest X coordinate is the intersection between keel and transom and it can have an angle Ta going from 90° to 104°. In the case of the back way inclination the point with the smallest X coordinate is the one at the deck intersection and it can have an angle Tb going from 90° to 105°. In some cases, the transom is built with a first segment connected with the keel, that can be perpendicular to the waterplane or inclined with an angle Twd that can reach 12° and a second inclined segment, that runs up to the deck. The inclination angle Twu of the second segment goes from 19° to 50°. The fastest planning motor yacht have a surface with the step. This kind of design element is a strip of hull parallel to the waterplane, its width Sl can vary from 1% to 4% of the length overall. Its length is equal to the length of the chine. The angle Bs is the angle between the step and the upper surface, the range of values of this measure goes from 57° to 105°. The angle As, which is the angle included between the step and the lower part of the hull, can vary between 191° and 231°.

MODELLING METHODOLOGY

As it happened between displacement motor yacht and displacement sailing yacht, also between displacement motor yacht and planning motor yacht there are some similarities. Since some parts of the two hulls behave in the same way it has been possible to use the script of some displacement form curves to code the planning yacht parametric hull. it is decided to use the same code for the sheer line, the deck line, the bow line, and some steps of the transom. The transom is composed of four lines. PM and MN are constructed starting from the same points of the displacement hull, but they are connected with straight lines. Point O is a new point, that lies on the vertical base plane YZ. The parameters to control it are the distance from the centreline plane (To) and the angle (Tp) included between the segment OP and the XY plane. The keel line has been created after the transom, this form curve is composed of three points, the lower point of the transom, the lower point of the bow and the point corresponding to the end of the straight segment of the keel. The parameters to control the shape of the form curve are the tangent at the bow connection point, the tangent at the transom point, the length of the straight segment and the tangent at the straight segment point end. The cross section is composed of two interpolated curves, that lie on a YZ. The parameter Xc controls the longitudinal position of the cross-section. The upper curve goes from the deck line to the chine line and the lower one goes from the chine line to the keel line. There are other four parameters connected to this form curve, each one of them controls one angle. The last form curve modelled for the creation of the surface is the chine line. Three control points permit the shaping of this form curve, one at the transom, one at the cross section and on at the bow. Each point has a parameter that controls its Z coordinate along the length of the respective curve (Za, Zs, Zb). The chine line created has other two parameters to permit a better control over its shape. The first one (Ct) relates to the tangent at the transom point and the second one (Cbb) is connected to the tangent at the bow point. From the form curves is created one surface for the transom (B) and four surfaces for the hull, the forward bottom one (E) is generated in between cross-section, chine line and profile, the aft bottom one (C) is in between transom line, cross section, keel line and chine line, the side forward one (D) is between bow line, cross section, deck line and chine line and the aft side one (A) is between the transom the cross section the deck line and the chine line. As well as the other models, the script regarding the forward calculations have been applied to the hull surface.

VALIDATION

The chosen model for the validation is an outboard motorboat, which hull present one chine running from transom to bow. Using Rhinoceros 3D on the Lines Plan of the Sitka Spruce all the main curves needed to build the surface have been highlighted with a thick red line. The drawing has been quoted so that all the Grasshopper input parameters have been extracted from the image.

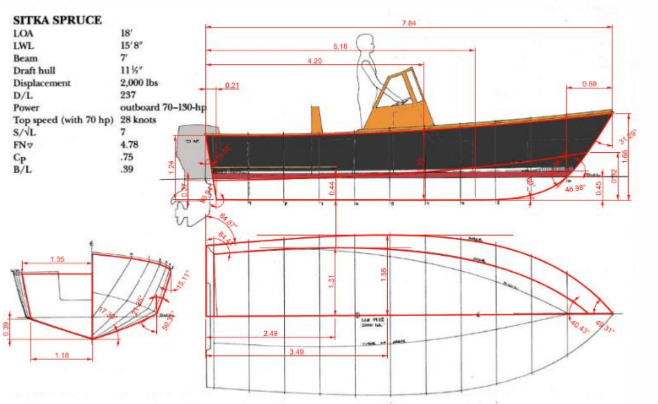

Figure 3-9: Quotes taken with Rhinoceros onto the Sitka Spruce motorboat Lines Plan.

Once completed the process of data extrapolation all the values have been inserted in the Grasshopper code. The script produced the violet lines, which have been superimposed on the drawing of the Sitka Spruce, so that it is possible to compare the model created by Grasshopper and the target model.

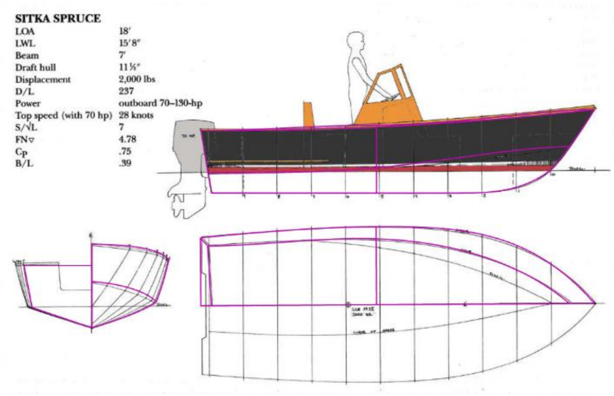

Figure 3-10: Construction lines created by Grasshopper code compared with the Sitka Spruce Lines Plan.

As it is possible to notice from Figure 3-10 the deck line, the keel line, the bow line, and the transom line follow the target lines of the chosen model. The chine line trajectory is the one that presents the bigger error, since from the cross-section to the bow contour it does not follow the trajectory of the target chine line.

Table 3: Offset table of the model produced by Grasshopper's code.

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
WL1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
WL2	0.00	0.71	0.74	0.77	0.81	0.85	0.89	0.91	0.91	0.86	0.76	0.65	0.56	0.46	0.36	0.26	0.15	0.03	0.00	0.0
WL3	0.00	1.21	1.23	1.25	1.28	1.31	1.33	1.35	1.35	1.34	1.31	1.26	1.14	0.97	0.79	0.61	0.44	0.26	0.06	0.0
WL4	0.00	1.28	1.31	1.34	1.37	1.40	1.42	1.44	1.44	1.44	1.42	1.39	1.34	1.27	1.16	1.02	0.84	0.61	0.35	0.0
WL5	0.00	1.35	1.38	1.41	1.44	1.47	1.49	1.51	1.52	1.52	1.51	1.49	1.46	1.41	1.34	1.23	1.08	0.88	0.62	0.3

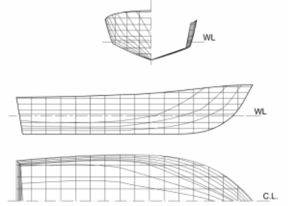

Figure 3-11: Planning motor yacht, line plan produced by grasshopper.

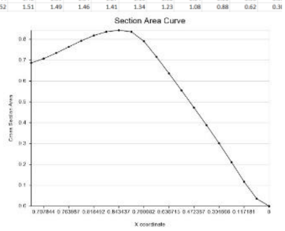

Figure 3-12: Cross section area curve generated by the planning motor yacht grasshopper code

4 CONCLUSIONS

In this Thesis were developed methodologies for the automatic generation of surface models of leisure craft hulls, using a software tool for visual parametric geometric modelling. The parameters used in the Grasshopper scripts are mostly geometric magnitudes such as linear dimensions and angular values.

In the code of the sailing boat, six lines were used to create two surfaces to represent the hull and the transom. In the validation, as overall, the main curves produced presented a good accuracy. The only line which the code is not able to reproduce accurately is the transom line.

Regarding the displacement hull for motor yachts, the lines and the surfaces used are the same of the sailing yacht ones. The final output of the design waterline and the profile curve were considered suitable. The deck line, although well shaped from the top view, appears to have a bit different trajectory. The transom rounded curve and the cross-section curve do not manage to perfectly reproduce the motor yacht ones.

The lines used to create the planning hull are the deck line, the transom line, the profile, the chine and the cross section. The output of the main curves has a good precision, except for the chine line. The code of the planning motor yacht hull is the one that needs to be improved the most, it is far from reproducing the large number of geometries that this type of hulls can assume.

Regarding future work, in general, more hull form coefficients should be introduced as parameters for a better control of the resulting hull form. The validation could have been done comparing output coefficients and dimensions calculated by the script, but the lack of data of the validations' lines plans didn't permit following this methodology. The study of the planning crafts' forms does not involve all the possible shapes

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