A mathematical model for Bodrum type gulet vessels' series

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ABSTRACT: The aim of this study is to mathematically model Bodrum type gulet vessels' series, starting from a working vessel with a good performance in all aspects of seakeeping. Considering the fact that only one vessel is insufficient in building up a serie form, some other similar (to the main vessel) vessels were generated with One Minus Prismatic Coefficient distortion method. Some offsets were acquired and these offsets were nondimensionalized to graph nondimensional offset vs. prismatic coefficient values. Acquired equations were found by some numerous numerical analysis methods and these equations were used to compose each station of the vessel. Curves included in the aft, fore, sheer and keel parts of the vessel were generated similar to that of the main vessel. As a part of the study, a program that creates the hull of the gulet in accordance to the desired main dimensions is developed. From this program, a vessel having the same dimensions with the main vessel was generated and their hydrostatic and resistance characteristics were compared.

1. INTRODUCTION

Gulet vessels were born in Holland and were seen in America via Britain and from there came back and spread to Europe over Italy and France. These vessels were firstly used for fishing and transportation while they were also used for military purposes. As maybe known, Gulets were first used in the Aegean Sea for carrying wine and other cargo and throughout the history they were used for many other purposes as well.

As tourism has entered into a developing stage in Turkey at the late 60's, tourists visiting Bodrum, Marmaris and the vicinity has increased significantly. Beauties of the virgin bays in these areas have attracted the tourists attention. However, insufficient number of boats that can carry these explorer tourists and the increasing interest in these areas have directed the tour organizators to seek for alternative solutions. To provide this increasing demand, some gulets that were used for fishing were modified – cabins over the main deck and seats on the aft deck were built to constitute the ancestors of today's Bodrum Gulets. The continuous development of tourism in the vicinity of Bodrum and the day by day increasing demand on these vessels have caused these gulets to evolve in a good way to reach today's widely known Bodrum Gulets.

The word 'gulet' probably derives from the Italian goleatta or French gouletté. The term of goletta was a synonym of "schooner" which is a type of sailing vessel characterized by the use of fore-and-aft sails on two or more masts with the forward mast being shorter or the same height as the rear masts. In the 16th or 17th century, schooners were first used by the Dutch sailors and then made a noticeable progress in North America about the 18th century. The classic Gulet supplies a great usage area with a rounded aft and they are usually known to be low to the water. Gulets are usually made up of local pine which are two – masted wooden vessels. Their main usage in the southern coasts of Turkey was fishing and transportation along the coast. Gulets are typically designed with a sharp and a raised bow, broad beam and rounded aft. The main idea behind the designs of gulets bear comfort rather than trade.

Bodrum hosts an International yacht festival which is called as The Bodrum Cup specializing on the wooden boats. In this festival, vessel forms usually play the major role in winning the cup, therefore, each year the interest on the development of the hull form of these boats increases. At this point, Turkish type Gulets seem to provide a good choice as a hull form. Turkish type Gulet form has a unique vessel form which resembles to the original gulet form.

As explained above, previously used for fishing, sponge hunting and cargo transporting; gulets maintained its special appearance but after they were used for "Blue Voyage" in traveling the Aegean and Mediterranean regions of Turkey, the form and the structure changed with time to complete Turkish type Bodrum Gulet's evolution. They are known and recognized as "Turkish type Bodrum Gulets" in the world and each year the interest in this type of boat increases. The main concern of this study is to protect the previously experienced forms of the gulets and in the same time maintain a Bodrum Gulet with the desired dimensions – whose form is mathematically defined within the study. These mathematical relations were flown into a computer program which creates a 3 – D model of the gulet to easily own a Bodrum Gulet design (Kükner et al., 2008).

To force a shipyard to accelerate its production, design and planning cooperation is significant. A good design leads to a good planning while a good planning increases production quality and speed. Therefore, a good design is essential in the first place.

If taken a look at customer – shipyard relation, first of all the customer defines the vessel to be owned and requests a price offer. Then, keeping an eye on the shipyard's facilities, the customer's needs are evaluated to offer a reasonable price. Keeping this dialogue stage as short as possible and making a good cost assumption is crucial for the shipyard to get the job and increase the profit. This whole scene is named as the predesign phase which may also be called as feasibility study.

The subject of this study is to develop a computer program in the predesign stage which helps to make quick and right calculations by producing a gulet form. As said, a long dialogue stage creates the risk of losing the customer therefore to reply as soon as possible increases both the prestige of the shipyard and the amount of spent work force. Quick and right predesign is the hinge of the design stage to create a strong planning which will at last lead to qualitative production.

2. THE METHOD OF THE STUDY

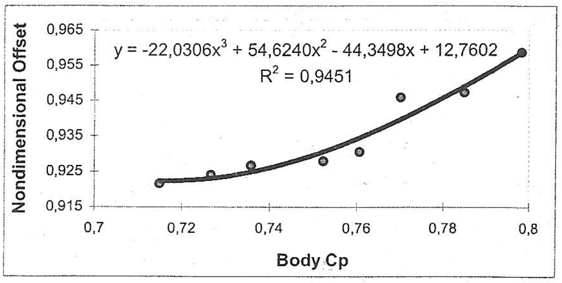
In this study, a working vessel of overall length 33.85m is taken into consideration. The offset of this vessel is given below:

Table 1. Offset of the main vessel.

OFF - SET TABLE									
Station No.	Half Beam (meter)								
	WL-3	WL-2	WL-1	WL 0	WL 1	WL 2	WL 3	WL 4	WL 5
0	0	0	0	0	0	0	0,016	2,059	3,028
0,5	0,165	0,165	0,165	0,179	0,224	0,43	1,579	2,813	3,391
1	0,165	0,165	0,202	0,305	0,538	1,082	2,285	3,212	3,61
2	0,165	0,165	0,337	0,672	1,156	1,948	3,044	3,618	3,813
3	0	0,165	0,331	0,812	1,462	2,402	3,35	3,76	3,876
4	0	0,165	0,247	0,855	1,622	2,6	3,461	3,805	3,893
5	0	0,165	0,165	0,787	1,6	2,569	3,438	3,795	3,887
6	0	0,165	0,165	0,627	1,399	2,311	3,223	3,691	3,829
7	0	0	0,165	0,417	1,069	1,893	2,773	3,407	3,659
8	0	0	0,165	0,165	0,624	1,246	2,049	2,755	3,21
9	0	0	0	0	0,179	0,492	1,027	1,64	2,174
9,5	0	0	0	0	0	0,18	0,504	0,949	1,441
10	0	0	0	0	0	0	0	0,192	0,515

The offset of the main vessel above is not sufficient by itself to totally form a new serie form therefore 9 new vessels were created with different prismatic coefficients. While creating new vessels, "One minus prismatic coefficient" method was used to skid the stations to change the prismatic coefficient. Then using the values included in these 10 offsets – for each station in each waterline – nondimensionalized offset vs. prismatic coefficient graphs were drawn and equations of the resultant curves were calculated using an Excel based working program, XLStat. All corelation values for these curves were found to be acceptable although some areas in the aft and fore parts of the vessel had accordingly low corelation values. Some graphs are given below for illustration.

The prismatic coefficient of the vessels are calculated only for the body part of the vessel which lies inside the outer boundary drawn by 13 stations and 5 waterlines. The stern, the bow and the keel parts were not included due to insufficient offset and drawing.



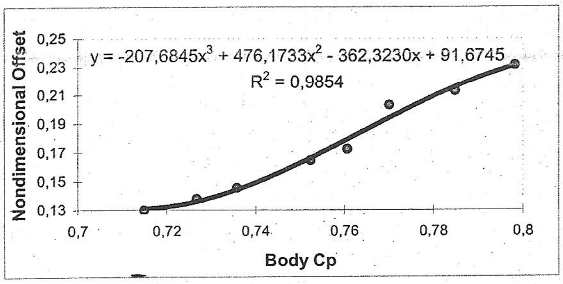


Figure 1. (above) WL4, St. 3 Graph and Equation, (below) WL2, St. 1 Graph and Equation

3. SIMILAR DESIGN PRODUCTION METHOD

There are many methods to create new vessels from an existing vessel which include Lackenby's Method, One Minus Prismatic Coefficient Method and Moor's Method. The method used in this study is One Minus Prismatic Coefficient Method which is one of the most reliable ways of creating a new vessel with a different prismatic coefficient from the main vessel. With this method, a vessel's prismatic coefficient and longitudinal center of buoyancy (LCB) is quite easy to change. The method's main idea consists of sliding the stations by a calculated value in a waterline and thereby gain a new vessel form. The main target is to achieve the desired C_p and LCB but while trying to catch up with the desired values, one should take care of not spoiling the curve.

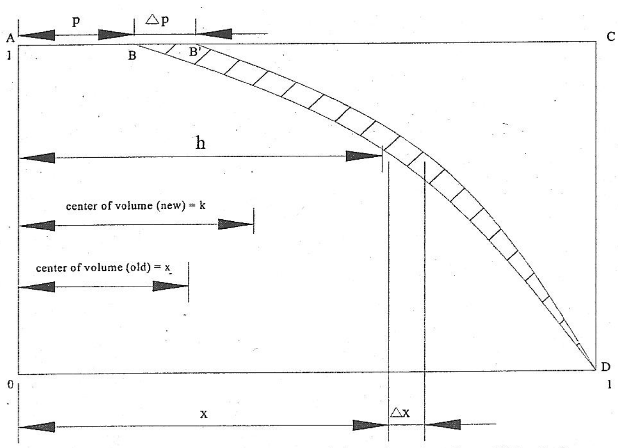


Figure 2. The change in center of gravity in the slided form of the vessel

A ΔC_p change in the prismatic coefficient is in direct proportion with how much the stations are moved. In this case sliding amounts of the stations may be found with equations given below:

$$\frac{BB'D}{BCD} = \frac{\delta x}{1-x} \tag{1}$$

$$\delta x = \frac{\delta C_p}{1-C_p}(1-x) \tag{2}$$

Due to the slided stations, there will be an elongation in the parallel body. As may also be noticed from the figure above, this elongation will be equal to Δp. This change in p is found with this relation given below:

$$\delta p = \frac{\delta C_p}{1-C_p}(1-p) \tag{3}$$

While changing the prismatic coefficient, to keep LCB staying in the same position, C_p's must be evaluated differently. In this case two different prismatic coefficients will be needed. The slided amount in the stern will be named ΔC_{pa} (aft prismatic coefficient) while it is named ΔC_{pf} (fore prismatic coefficient) in the bow.

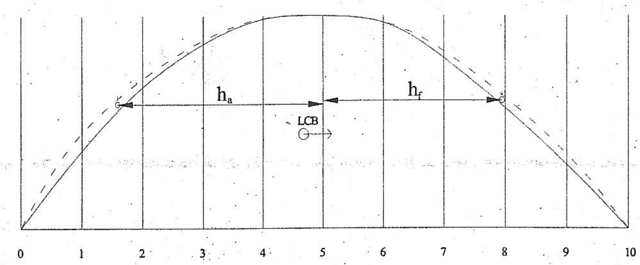


Figure 3. The position of changing LCB.

The sliding amounts of the stern and the bow may be found with the relations given below (Sarıöz, 2006):

$$h_f = \frac{C_{pf}(1-2\bar{x}f)}{1-C_{pf}} + \frac{\delta C_{pf}}{2(1-C_{pf})^2}\left[1-2C_{pf}(1-\bar{x}f)\right] \tag{4}$$

$$h_a = \frac{C_{pa}(1-2\bar{x}a)}{1-C_{pa}} + \frac{\delta C_{pa}}{2(1-C_{pa})^2}\left[1-2C_{pa}(1-\bar{x}a)\right] \tag{5}$$

4. ABOUT THE PROGRAM

At the end of the work, a serie form for gulets having a body prismatic coefficient between 0.7 and 0.8 were acquired and the date attained from all the graphs were flown into a computer program. Although these vessels are somewhat chubby, to include vessels familiar to the original gulet form, the prismatic coefficient is chosen to be between 0.7 and 0.8. The program is developed to model Bodrum type gulet of desired dimensions in Autocad. The coded program requests 4 major dimensions of the vessel – which are waterline length, waterline breadth, waterline depth and body C_p respectively – and models the vessel 3 – D according to the mathematical identifications lying inside of the program. The program also gives the offset of the body in Excel. The main screen of the program is given below:

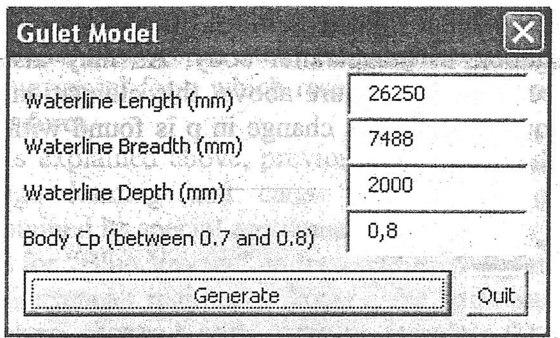


Figure 4. The appearance of the program

The body C_P requested in the program covers the part of the hull that lies under the design waterline. However the body C_P does not cover the keel part of the vessel. The figure below tries to explain the difference between the prismatic coefficient and the body prismatic coefficient.

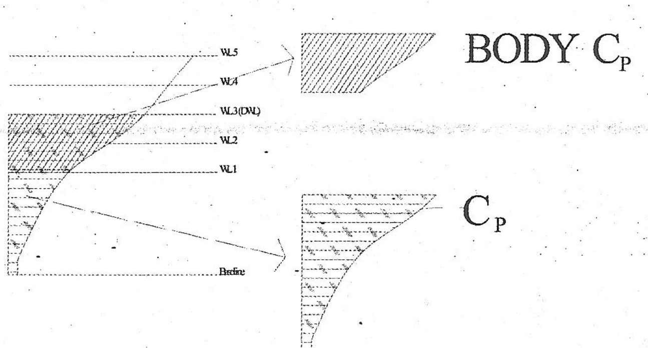


Figure 5. The difference between C_p and the Body C_p

The modeled vessel consists of stations, waterlines, sheer and keel with curves included in the aft and fore. The station curves are obtained from the equations acquired from the graphs. Equations of the third degree are found to best fit the given points for the station curves therefore general definition of the equations are as follows:

$$y = at^3 + bt^2 + ct + d \quad (6)$$

The "t" variable in the equation refers to the Body C_P in the program's main screen while "y" is the nondimensionalized offset value for that station. This nondimensionalized offset is multiplied by the Waterline Breadth in the program to give the real offset value.

The graphs that are explained before is for every station in each waterline therefore waterline curves are automatically obtained. The program connects each related point with a spline curve to compose each waterline.

Direct proportion principle is used for curves included in the sheer and keel. Unlike curves included in the waterlines and stations, sheer curve is a 3 – D curve. In the main vessel, the distance between the sheer and the 5^{th} waterline is measured for each station and the values are nondimensionalized by dividing each value by the Waterline Depth that must be supplied in the program's main screen. The same principle is followed while calculating the breadth of the sheer. The distance between the sheer and the centerline is measured for each station and the values are nondimensionalized by dividing each value by the Waterline Breadth in the program. After completing these processes, there are enough numbers to create a 3 – D spline curve for the sheer. The same systematic is used for the keel part of the vessel.

While forming the bow and stern part of the vessel – due to the insufficiency of the main vessel's offset – new stations were added. These stations are not shown in the modeled vessel that is produced by the program. The only reason to add these stations is to produce a smoother curve when connecting the sheer and the keel. If these additional stations were not taken into account, for example, the sheer curve between the 10^{th} station and the fore extreme would look like as if it was linear. The flowchart of the program is given in the appendix.

5. THE COMPARISON OF THE GENERATED VESSEL AND THE MAIN VESSEL

When the dimensions of the main vessel is entered to the program that is developed for this study and made a comparison between the two, there seems to be 3 – 5 mm of difference in the sections but the profile view is about the same. If the plan views of both of the vessels' are put on top of each other, it can be seen that there is an obvious difference in the stern form. The main vessel's stern form is much more fatter than the generated vessel's stern form. The reason for this is (as said before) insufficiency of the main vessel's offset in the stern. More accurate results may be obtained if more stations are to be added to the stern of the main vessel. Comparisons may be observed closer in the appendix. In there, red lines refer to main vessel while black lines refer to the generated vessel.

If one thing is clear about the comparison, that is that the main vessel is fatter than the generated vessel. Therefore displacement of the main vessel is greater which produces more resistance in water and needs more powerful machines and propulsion system. The comparison table and the speed versus resistance graph is given below to take a closer look.

While calculating the resistance, Holtrop Mennen method is used. The displacement is only for the body part of the vessel (as said before; body part consists of the intersection of all the waterlines and the stations)

Table 2. Resistance comparison of the main vessel and the generated vessel.

	Main Vessel	Generated Vessel	
Speed (knot)	Resistance (kN)	Resistance (kN)	Resistance Diff. (%)
1	0,0965	0,082	15,0259
2	0,3499	0,2972	15,0614
3	0,7457	0,6334	15,0597
4	1,278	1,0854	15,0704
5	1,9543	1,658	15,1614
6	2,8607	2,4099	15,7584
7	4,3103	3,5681	17,2192
8	6,4533	5,3004	17,8653
9	12,3123	9,5462	22,4662
10	18,6106	13,6656	26,5709
11	24,6534	18,9412	23,1700
12	39,5071	31,1963	21,0362
13	52,0907	40,6781	21,9091
14	52,2932	40,0396	23,4325
15	53,3675	39,8829	25,2674
16	55,1411	40,1178	27,2452
17	57,4706	40,6691	29,2349
18	66,145	46,1573	30,2180
19	75,0939	52,1091	30,6081
20	83,3598	57,759	30,7112
	Displ. (m^3)	Displ. (m^3)	Displ. Diff. (%)
	60,3882	47,9451	20,6052

Table 3. Comparison of wave resistance coefficient for the main vessel and the generated vessel.

		Main Vessel		Generated Vessel	
Spd. (knot)	F_n	R_W (kN)	$10^3 * C_W$	R_W (kN)	C_W
1	0.062	0	0	0	0
2	0.124	0	0	0	0
3	0.186	0	0	0	0
4	0.249	0	0	0	0
5	0.311	0.013	0.007	0.009	0.006
6	0.373	0.127	0.048	0.088	0.040
7	0.436	0.659	0.184	0.467	0.155
8	0.498	1.759	0.377	1.314	0.335
9	0.560	6.453	1.092	4.571	0.922
10	0.623	11.465	1.572	7.598	1.242
11	0.685	16.102	1.825	11.680	1.578
12	0.747	29.430	2.803	22.641	2.570
13	0.810	40.371	3.276	30.728	2.972
14	0.872	38.814	2.716	28.596	2.385
15	0.934	38.013	2.317	26.847	1.950
16	0.997	37.795	2.024	25.392	1.621
17	1.059	38.019	1.804	24.156	1.366
18	1.121	44.474	1.882	27.760	1.400
19	1.184	51.090	1.941	31.732	1.437
20	1.246	56.910	1.951	35.306	1.443
		Wet Area (m^2)		Wet Area (m^2)	
		142.266		**119.352**	

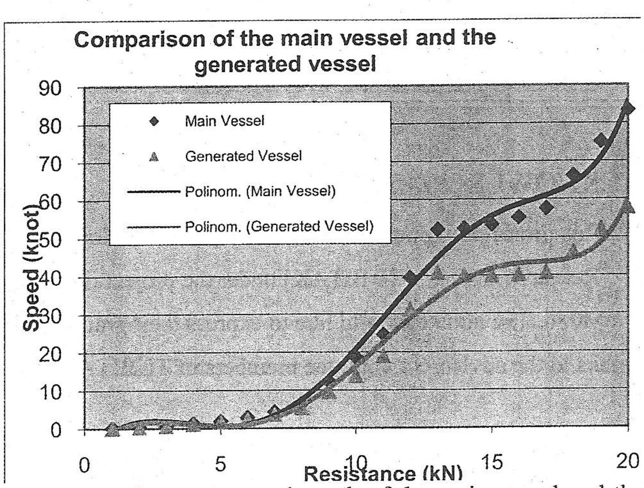


Figure 6. Resistance – speed graph of the main vessel and the generated vessel.

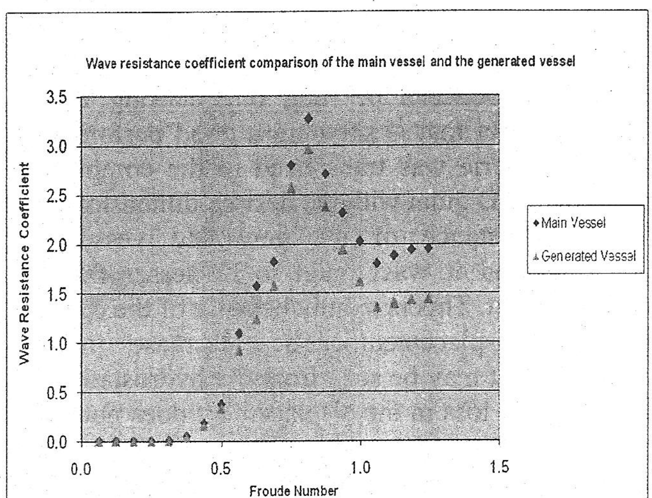


Figure 7. Wave resistance coefficient comparison of the main vessel and the generated vessel.

The difference of the hydrostatic values between the generated vessel and the main vessel is shown in Table 4. The main dimension of the generated vessel was chosen to be same as the main vessel and the rest of the hydrostatic values were compared.

Table 4. Hydrostatic comparison of the main vessel and the generated vessel.

BOAT CHARACTERISTICS	MAIN VESSEL	DERIVED VESSEL	DIFF. (%)
Length between perpendiculars (L_{BP}), m	26.25	26.25	0
Waterline length (L_{WL}), m	26.25	26.25	0
Beam (B), m	7.8	7.8	0
Draft (mastery) (T), m	2.745	2.745	0
Depth (D), m	3.25	3.25	0
Displacement Volume (V), m^3	120.776	95.890	20.605
Displacement (V * ro), ton	123.796	98.287	20.605
Waterplane area (A_{WP}), m^2	131.901	106.682	19.120
KB, m	0.774	0.758	2.142
BM_T, m	3.254	2.231	31.443
BM_L, m	40.849	40.805	0.107
KM_T, m	4.028	2.989	25.811
KM_L, m	41.623	41.563	0.145
Block coefficient (C_B)	0.205	0.162	20.605
Prismatic coefficient (C_P)	0.656	0.639	2.524
Midship section coefficient (C_M)	0.312	0.254	18.549
Waterplane area coefficient (C_{WP})	0.726	0.587	19.120
LCB (+ forward)	-1.348	-1.432	-6.232
LCF (+ forward)	-1.131	-1.255	-11.014

6. RESULTS

In this study; a serie form for Bodrum type Gulets was developed which have body prismatic coefficient between 0.7 and 0.8, starting from a working gulet that is showing a good performance. Then this serie was transferred to the computer to model a 3 – D gulet with the desired dimensions.

The resistance of the generated vessel was observed and it was found to be lesser than the original gulet. This is mainly because of the decrease in the displacement. The decrease in the displacement may be seen from the hydrostatic table as well. The loss in the displacement does not create major problems in accomodation. As the speed increases the resistance margin will get bigger and the generated vessel will be more preferrable.

The program is a predesign program rather than a design program. If developed, more effective results may be obtained. For example, in the models that the program produce there are curvilinear errors in some locations. It may be possible to get rid off these errors with a more precise work. Moreover, an additional program that detects these errors may be developed that works like a fairing mechanism.

The program may also do hydrostatic calculations and work two – sided. At the present, the program only takes the data from Excel and models the vessel in Autocad. However, the designer may want to interfere with the hull from Autocad as well. If the program can work in two – ways, the offset of the vessel and the hydrostatic calculations will differ as changes over the hull are made. The designer will catch the vessel according to his/her desire at one point in a shorter time.

REFERENCES

Akdoğan, R., 1997. Türkçe – İngilizce Ansiklopedik Denizcilik Sözlüğü, Sunar Matbaacılık

Holtrop, J., A Statistical Re – Analysis of Resistance and Propulsion Data

Holtrop, J. and Mennen, G. G. J., 'An approximate power prediction method', Internation Shipbuilding Progress, Vol. 29, July 1982

Kafalı, K., 1994. Gemi Formunun Statik ve Dinamik Esasları, İ.T.Ü. Gemi İnşaatı ve Deniz Bilimleri Fakültesi Ofset Baskı Atölyesi

Kükner, A. (project manager), Sarıöz K., Bal Ş., Akyıldız H., Aydın M., Turan F., Özalper F., 2008. Türk Tipi Guletlerin İncelenmesi ve Form Optimizasyonu / Gelişme Raporu I, TÜBİTAK 106M086 No.'lu Proje

Larsson, L. ve Eliasson, R., 2006. Yat Tasarımı Genel İlkeler, Birsen Yayınevi, İstanbul

Sarıöz, K. ve Sarıöz, E., Haziran 2006. Gemi Tekne Formlarının Geometrik Dizaynı, Kansu Matbaacılık, İstanbul

Taylor, D. W., 1943. The Speed and Power of Ships, U.S. Government Printing Office

Tc Genelkurmay Başkanlığı Deniz Kuvvetleri Komutanlığı, 1991. Gemicilik Sözlüğü, Deniz Kuvvetleri Komutanlığı, İstanbul

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App – 2

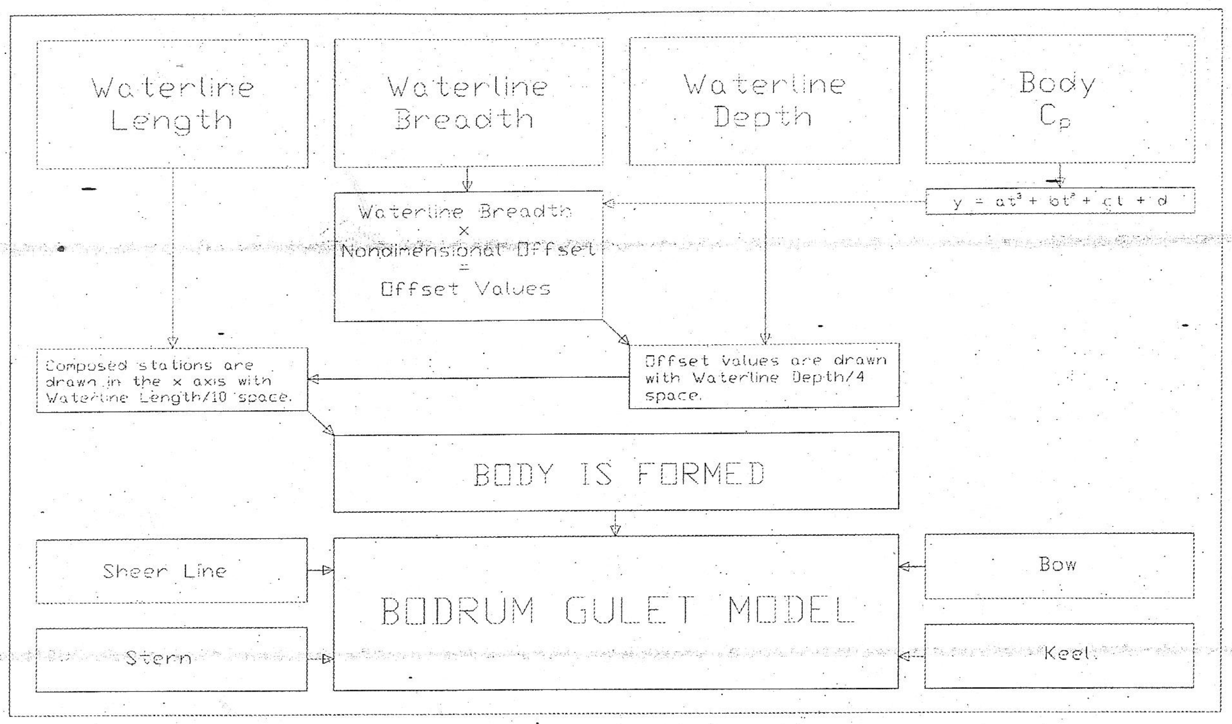

Figure 9. The flowchart of the program

App – 3

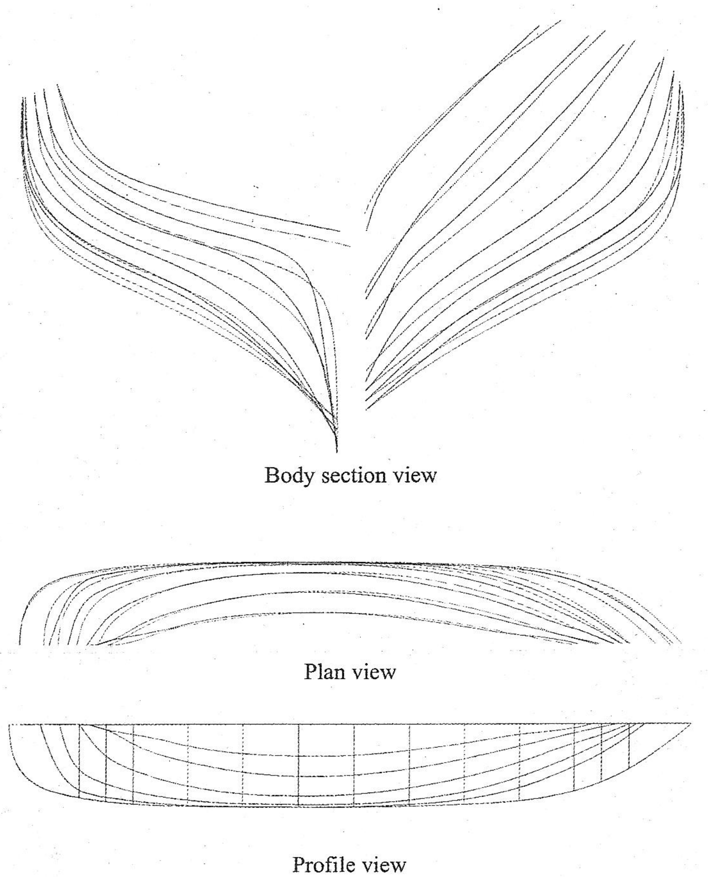

Figure 10. Comparison of the main vessel and the generated vessel.