Uncertainty in the reconstruction of the ancient ship hull and its impact on sailing characteristics

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SCOPE OF RESEARCH

The study of ancient ships, shipbuilding and seafaring is partly based on shipwrecks, that is the remnants of ships and cargos on the bottom of the sea. Over the centuries, natural forces influence the degradation of the hull, and commonly, the ships just partially survive. Consequently, reconstruction of the hull lines becomes a complex task, and in the attempt to complete the task, uncertainties must be replaced by sound estimations. Therefore, the reconstructed hull lines are the result of the best estimation and may differ from one designer to another, instead of being perfectly reproduced as for the newly built ship. This partially subjective decision making, which proves to be inevitable, could result in slight variations in the final result. The scope of the presented research is to explore the effect of slight variations of ship hull lines, namely ship width, on the performance of the ship, namely her speed, stability, and capacity of the cargo hold.

METHODOLOGY

The 4th century BC Greek merchant ship found near Kyrenia on Cyprus was chosen for case study. The Kyrenia hull lines *(Fig. 1)* are available in the scientific literature (Steffy 1994). Based on Steffy's hull lines drawing, the hull form was generated with the help of SolidWorks and Rhinoceros software. The SolidWorks software was used to generate the half-model, by carefully scaling and drawing the keel, stem, sternpost, and frames in corresponding frame planes. This half-model was then imported into Rhinoceros software, mirrored, and cleaned of unnecessary geometry elements *(Fig. 2)*. As the result, a Kyrenia hull model was generated. An estimation of the mass of the ship was done based on the photograph of the unloaded replica Kyrenia Liberty *(Fig. 3)*. The mass of Kyrenia hull structure was estimated to 9 tons. In that case, when the distance from the waterline to sheer strake measures 80 cm, the mass of the fully loaded ship is 22 tons. That corresponds to 1.36 m draft of the hull model. Diminishing the distance from the waterline to sheer strake would give the possibility of loading more cargo, increasing the draft, but decision was taken to proceed with the above stated data. Finally, four additional hull models were generated, changing the width of the ship ± 5% and ± 10%. In total, five models were generated: hull width – 10%, hull width – 5%, original hull width, hull width + 5% and hull width + 10%. For each model the Holtrop method was applied for ship resistance analysis (on calm water). In addition, Computational Fluid Dynamics (CFD) analysis of ship resistance was made for the original hull model, in order to validate the Holtrop results.

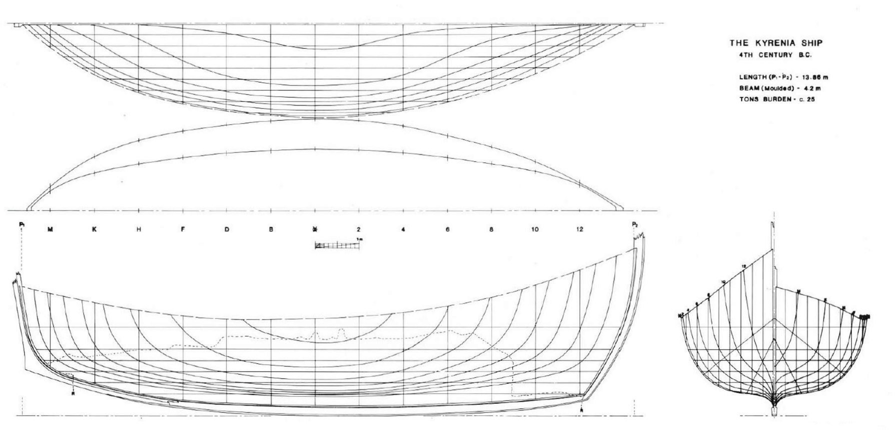

Fig. 1 Kyrenia hull lines (after Steffy, 1985)

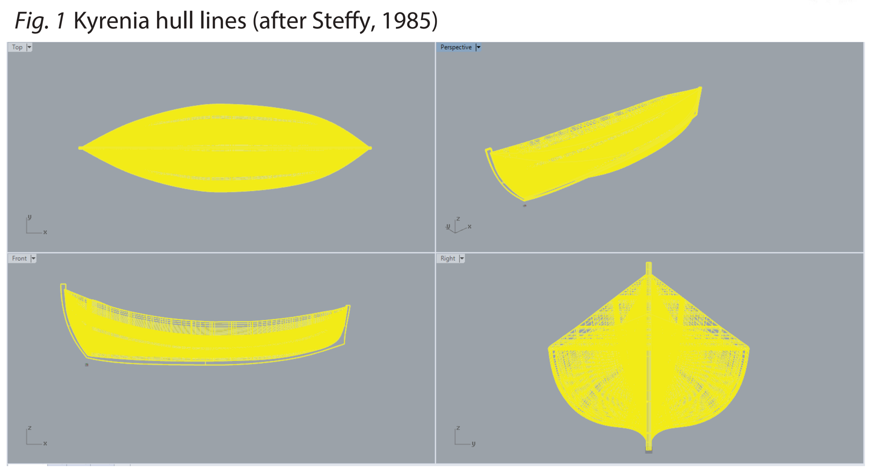

Fig. 2 Full model of Kyrenia ship in Rhinoceros software (model: G. Jerat)

Fig. 3 Kyrenia ship replica Kyrenia Liberty (photo: E. L. Evriviades)

DISCUSSION

Table 1 and Fig. 4 present the difference in fully loaded ship displacement for all five models. The original hull has a displacement of 22 tons at 1.36 m draft. For the same draft, a reduction of ship width by 5% gives a displacement of 20.95 tons; reduction by 10% gives 19.848 tons; an increase of ship width by 5% gives a displacement of 23.156 tons; and finally, an increase of 10% gives 24.259 tons. In other words, if draft was kept at 1.36 meters, and the distance from the waterline to sheer strake maintained at 80 cm, from slightly narrower to slightly wider hull form, the difference in mass of the fully loaded ship is 4.41 tons. This means that the 10% wider ship could carry about 2.3 tons more cargo, while still being equally seaworthy.

Hull form width	0.9B	Hull form width	0.95B	Hull form width	original	Hull form width	1.05B	Hull form width	1.1B
Draft	Displacement, t	Draft	Displacement, t	Draft	Displacement, t	Draft	Displacement, t	Draft	Displacement, t
0,1	0,05	0,1	0,05	0,1	0,05	0,1	0,06	0,1	0,06
0,2	0,12	0,2	0,13	0,2	0,13	0,2	0,14	0,2	0,15
0,3	0,22	0,3	0,23	0,3	0,25	0,3	0,26	0,3	0,27
0,4	0,41	0,4	0,43	0,4	0,46	0,4	0,48	0,4	0,50
0,5	0,81	0,5	0,86	0,5	0,90	0,5	0,95	0,5	0,99
0,6	1,70	0,6	1,79	0,6	1,88	0,6	1,98	0,6	2,07
0,7	3,07	0,7	3,25	0,7	3,42	0,7	3,59	0,7	3,76
0,8	4,85	0,8	5,12	0,8	5,39	0,8	5,66	0,8	5,93
0,9	6,98	0,9	7,36	0,9	7,75	0,9	8,14	0,9	8,53
1	9,39	1	9,91	1	10,44	1	10,96	1	11,48
1,1	12,06	1,1	12,73	1,1	13,40	1,1	14,07	1,1	14,74
1,2	14,92	1,2	15,75	1,2	16,58	1,2	17,41	1,2	18,24
1,3	17,96	1,3	18,96	1,3	19,95	1,3	20,95	1,3	21,95
1,4	21,13	1,4	22,31	1,4	23,48	1,4	24,65	1,4	25,83
1,5	24,42	1,5	25,78	1,5	27,13	1,5	28,49	1,5	29,85
1,6	27,80	1,6	29,34	1,6	30,89	1,6	32,43	1,6	33,98
1,7	31,26	1,7	33,00	1,7	34,74	1,7	36,47	1,7	38,21
1,8	34,79	1,8	36,72	1,8	38,66	1,8	40,59	1,8	42,52
1,9	38,38	1,9	40,51	1,9	42,64	1,9	44,77	1,9	46,90
2	42,01	2	44,34	2	46,68	2	49,01	2	51,35

T. 1 Displacements for various hull widths by the Holtrop method

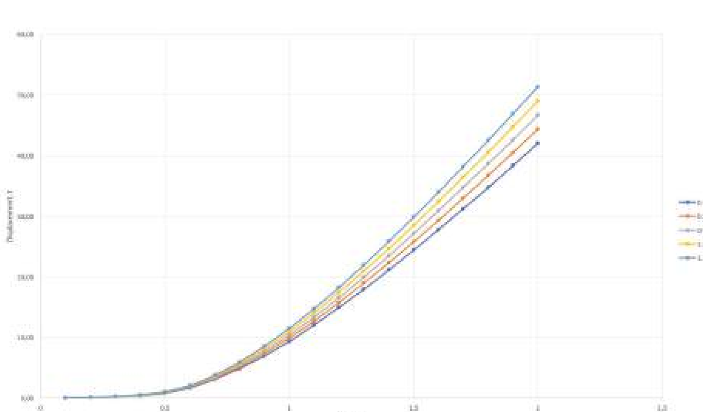

Fig. 4 Comparison of the results of the calculation of displacement for various hull widths by the Holtrop method

Table 2 and Fig. 5 present the ship resistance at different sailing speeds. For the estimated top speed of 4.5 knots, hull width - 10% model has resistance of 527.4N, hull width - 5% model 544.7N, original hull model 562.4N, hull width + 5% model 580.5N, and hull width + 10% model 599.2N. The relative difference between minimum and maximum resistance is 13%, meaning that the ship of the hull width - 10% would require 13% less force (sailing or rowing) compared to the ship of the hull width + 10%, when sailing with 4.5 knots.

Hull form width	0.9B	0.95B	original	1.05B	1.1B	CFD
Displacement, t	19,848	20,95	22,053	23,156	24,259	22
velocity, kt	Resistance, N					
0,5	9,2	9,5	9,9	10,3	10,7	7,321
1	32,6	33,9	35,2	36,6	37,9	28,781
1,5	68,6	71,3	74,1	76,9	79,8	
2	116,1	120,7	125,4	130,2	135	114,692
2,5	174,6	181,4	188,5	195,6	202,9	
3	243,4	252,8	262,7	272,5	282,6	250,787
3,5	322,7	335	347,8	360,7	373,8	
4	414,9	429,9	445,6	461,4	477,6	447,895
4,5	527,4	544,7	562,4	580,5	599,2	590,61

T. 2 Ship resistance at different sailing speeds for various hull widths by the Holtrop method, and the results of CFD analysis

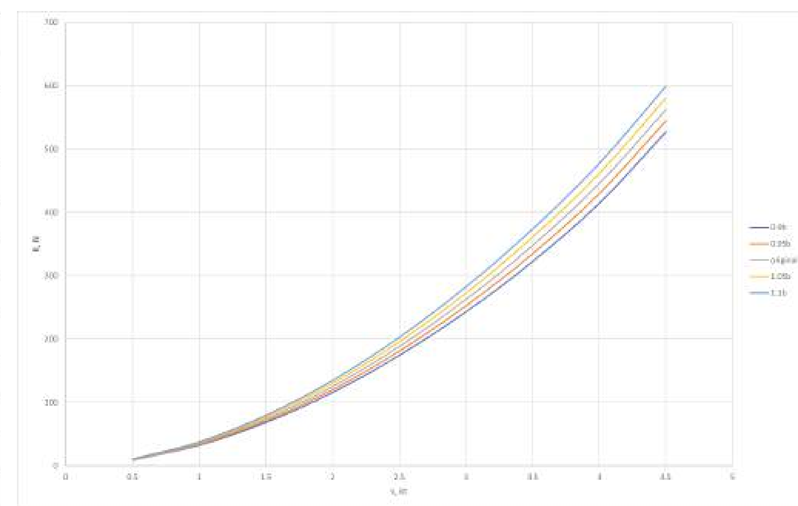

Fig. 5 Comparison of the results of calculation of calm water resistance for various hull widths by the Holtrop method

Table 2 also presents the CFD results for the resistance of the original hull form *(Figs. 7, 8)*, which can be compared with Holtrop results. Some differences may be noticed for low speeds, e.g., for 1 knot speed the Holtrop method estimates resistance of 35.2N, while the CFD method estimates resistance of 28.781N, which gives approximately the difference of 22%. For higher sailing speeds the difference becomes smaller, and for the speed of 4.5 knots the difference is only 5%. These results provide confidence in using the much simpler Holtrop method in ship resistance estimation, although caution is needed for slow speeds. Detailed comparison of the results of the two methods is provided in *Fig. 6*.

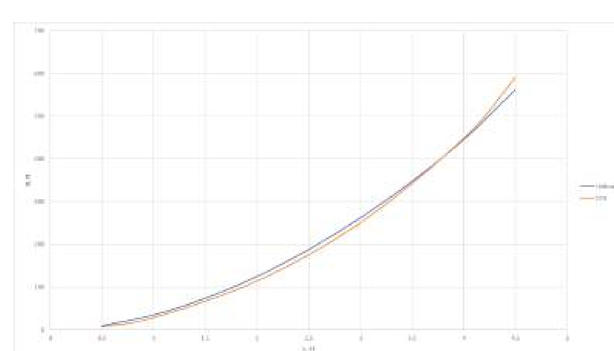

Fig. 6 Comparison of calm water resistance calculation results by the Holtrop method and CFD analysis of the original hull form

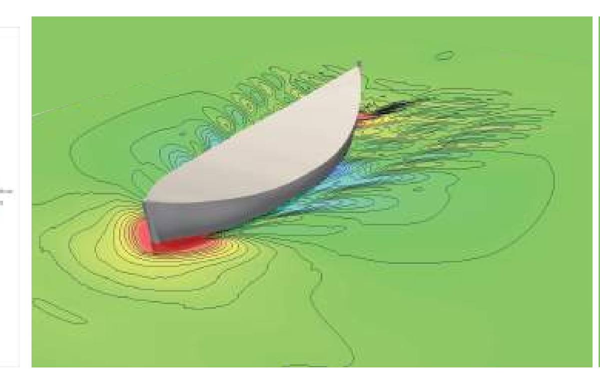

Fig. 7 Perspective view of calm water resistance CFD simulation with surface elevation (courtesy of Dr. Inno Gatin, In silico Ltd.)

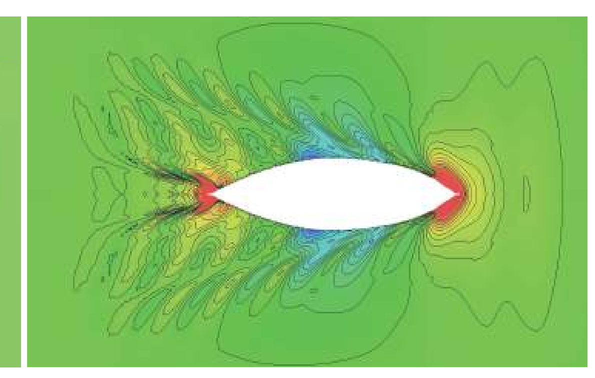

Fig. 8 Top view of the wavefield from the calm water resistance simulation (courtesy of Dr. Inno Gatin, In silico Ltd.)

Finally, the stability of the ship was analysed by calculation of stability arm and restoring moment, for rolling angle from 0 to 15º degrees, where 15º degrees is overturn angle for hull width + 10% variant. *Table 3 and Fig. 9* present the results. Obviously, for the hull width + 10%, ship restoring moment is much higher than for the narrower hull width - 10%, and the difference, for the maximum angle, is about 53%. As a further step of the research, scantlings calculation should be provided as well as variation of the structural arrangement and influence on the scantlings and joining parameters of the structural elements, which are closely related to better estimation of the displacement and draft.

Hull form	0.9B		Hull form	0.95B		Hull form	original		Hull form	1.05B		Hull form	1.1B	
angle, °	lever, mm	moment, Nm	angle, °	lever, mm	moment, Nm	angle, °	lever, mm	moment, Nm	angle, °	lever, mm	moment, Nm	angle, °	lever, mm	moment, Nm
0	0	0	0	0,00	0,00	0	0,00	0,00	0	0,00	0,00	0	0,00	0,00
1	37,00	7204,74	1	39,27	8070,34	1	41,65	9011,39	1	44,16	10031,71	1	46,79	11135,33
2	74,00	14407,36	2	78,52	16137,86	2	83,29	18019,06	2	88,30	20058,51	2	93,56	22264,78
3	110,97	21605,80	3	117,75	24199,78	3	124,89	27019,30	3	132,40	30076,48	3	140,27	33381,47
4	147,90	28797,97	4	156,93	32253,27	4	166,44	36008,34	4	176,43	40078,76	4	186,91	44479,52
5	184,80	35981,77	5	196,06	40295,69	5	207,92	44982,85	5	220,38	50062,39	5	233,44	55553,05
6	221,64	43155,43	6	235,13	48324,58	6	249,32	53939,51	6	264,23	60022,49	6	279,84	66595,19
7	258,42	50316,99	7	274,11	56337,03	7	290,62	62874,16	7	307,95	69954,13	7	326,09	77601,02
8	295,13	57463,95	8	313,01	64330,21	8	331,80	71783,37	8	351,52	79851,44	8	372,15	88563,70
9	331,75	64594,43	9	351,79	72301,17	9	372,85	80662,72	9	394,92	89710,49	9	418,00	99475,36
10	368,28	71705,85	10	390,45	80246,32	10	413,74	89508,54	10	438,13	99525,39	10	463,62	110330,13
11	404,69	78795,77	11	428,97	88163,25	11	454,45	98316,68	11	481,12	109291,25	11	508,97	121123,09
12	440,98	85862,26	12	467,33	96048,70	12	494,97	107083,65	12	523,88	119004,13	12	554,02	131844,44
13	477,14	92903,04	13	505,54	103899,81	13	535,29	115805,10	13	566,36	128655,21	13	598,75	142490,25
14	513,16	99915,65	14	543,55	111712,64	14	575,36	124474,83	14	608,57	138242,52	14	643,15	153053,66
15	549,01	106896,79	15	581,36	119483,97	15	615,20	133092,88	15	650,48	147762,14	15	687,17	163530,74

T. 3 Stability arms and restoring moments for various hull widths by the Holtrop method

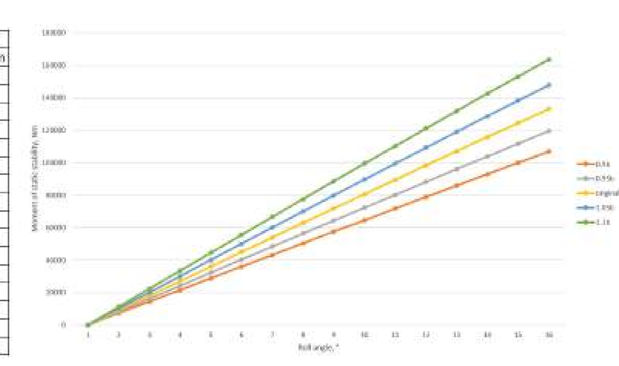

Fig. 9 Comparison of the results of calculation of restoring moments for various hull widths by the Holtrop method

CONCLUSION

The aim of the presented research is to estimate the effect of slight variation of just one hull parameter, namely ship width, on ship performance. While some conclusions are obvious, e.g., that the narrower ship will be lighter and that a wider ship will require more force for the same sailing speed, analysis revealed that the other differences are not negligible (even if only 5% and 10% of hull width variations are considered). Successful ship design consists in balancing contradicting requirements: to sail as fast as possible, to carry as much cargo as possible, and to be as light (cheap) as possible. During the ship hull reconstruction and in the case of missing data, uncertainties must be replaced by the logic of design engineers and craftsmen. However, slight variations in hypothetical data significantly affect the reconstructed ship performance, even if just one of many possible parameters are varied. Additional sources of data could help us to support the proposed reconstruction of the hull lines, or ± 5% to ± 10% hull width variations, such as historical records of the required travel time or historical priorities (fast delivery, cost of travel etc.). Particular attention should be made in the process of construction of ship replicas.

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