PARAMETRIC FORMULATION OF THE FLOODABLE LENGTH CURVE: APPLICATION CASE TO OFFSHORE PATROL VESSELS

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SUMMARY

The residual buoyancy of vessels after damage has a fundamental role in their survivability and it is implemented through adequate ship internal subdivision. Traditionally the number and the position of transverse watertight bulkheads are selected for most ships early in the design phase by means of the "floodable length curve" coupled with the concept of "margin line". However, for naval vessels, it is more and more common during the acquisition process to explore a wide domain of feasible ships, identified with the assistance of automated processes and assessed also in terms of capabilities, among which is survivability. The generation and the comparison of a considerable number of different ship configurations is very time consuming. Therefore recourse to a parametric expression of the floodable length curve is considered to be a very efficient approach and would thus enable characterisation of the ship, in terms of survivability performance. In this paper such an approach is presented, using an offshore patrol vessel (OPV) as the case study.

1. INTRODUCTION

The reserve of buoyancy after damage is one of the fundamental aspects characterizing the ship survivability; to this aim, watertight transverse bulkheads are the most effective way to control the severity of consequences when a flooding is given.

In the field of passenger ships, for nearly a century, the number and the position of such watertight transverse bulkheads along the ship have been decided thanks to the floodable length curve (SOLAS,1974; Tupper, 2013; Lewis, 1988), based on the identification of a margin line, i.e. an ideal threshold on the ship sides that shall not be exceeded by the final waterline in case of damage. However, at present, the so called probabilistic SOLAS 2009 (IMO, 2006) does not rely anymore on this approach.

The margin line concept nevertheless is still the backbone of the design process for naval vessels (Sarchin & Goldberg, 1962; NAVSEA, 2016), when dealing with the fulfilment of safety design criteria in case of damage and therefore when dealing with survivability.

In the context of naval ships acquisition process, it is often necessary to enlarge the investigated design domain by means of automated calculation procedures (Brown & Thomas, 1998; Kerns, 2011; Jones, 2014): evaluating and comparing a significantly large number of different ship configurations in terms of performances, i.e. pre-identified capabilities and tasks (Bertolotto *et al.*, 2009), (Salio *et al.,* 2014), (Perra *et al.,* 2015), it is possible to look for the most favourable solution in terms of cost /effectiveness ratio.

The whole computational architecture for the automated "ship generator" should be properly developed in turn to obtain a balanced performance in terms of speed and accuracy, when delivering feasible ships for the above mentioned capability assessment procedure.

To allow for a basic survivability assessment in terms of residual buoyancy, after the naval vessel geometry has been generated, the number and length of the compartments should be decided in fulfilment with constraints like: "the ship compartment should not be shorter than"; but also: "the ship compartment should not be longer than".

This upper limit can be enforced making reference to the floodable length curve. To do that, it is necessary to link the automated hull generator software with another one, typically used during the ship design for the mandatory intact and damage stability assessments. This passage would be very time consuming from the computational point of view, therefore in this paper we propose an approximate but reasonably effective method to identify the floodable length curve by means of a parametric approach.

The proposed formulation relies on an initial investigation on hulls modified in a series of parent hulls; it is usable knowing very little information of the investigated vessel of the same typology.

The preliminary study and the development of the formulation will be described for an offshore patrol vessel. The final outcome has been validated in conclusion with its application to different existing patrol vessels in order to ascertain the order of magnitude of its possible inherent error.

2. DEVELOPMENT DATABASE FOR THE PARAMETRIC FORMULATION

To carry out the analysis, an Offshore Patrol Vessel (OPV) has been selected as an application case (Figure 1). OPVs are very interesting due to their versatility in terms of size and in relation with the different operational requirements they are requested to meet. They can be designed to control domestic waters with the ability to carry out long term missions, humanitarian relief and to participate in international task force. Their performance in terms of effectiveness can be enhanced thanks to trade-off analyses carried out in the preliminary design phases.

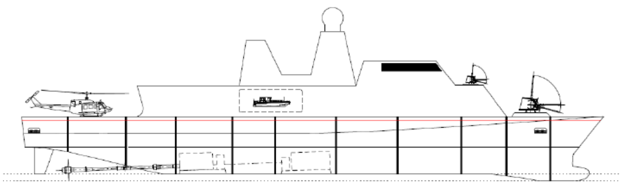

Figure 1: Typical longitudinal profile of an OPV

In this paper, the possibility to identify the number and the arrangement of the watertight bulkheads for an OPV type vessel has been analysed, with the aim to produce a parametric floodable length curve, to be applied since the very early stages of the design process.

By an investigation and a statistical post-processing of an OPV database derived from Jane's collections (Saunders, 2015), a range of values for a systematic hull generation was taken into account, assuming as original parent hull a real OPV unit of nearly 90 m in length.

Other hulls have then been obtained by systematic geometrical changes and the floodable length curve has been calculated for each of them, with the aim to observe the relevant variations, as a consequence of the ship geometrical changes.

The main ship parameters and ratios which have been considered are the following:

L	Length (m)
B	Breadth (m)
D	Depth (m)
T	Draught (m)
Δ	Displacement (t)
F	Freeboard (m)
VCG	Vertical Centre of Gravity (m)
LCG	Longitudinal Centre of Gravity (m)
∇	Immersed Volume (m^3)
L/B	
B/T	
D/T	
D/B	
F/D	
$L/\nabla^{1/3}$	

A total of 70 cases have been generated and better identified in a table provided in Annex 1. For sake of completeness, the investigation has actually processed 75 cases to assess also the VCG variation effect, that subsequently has been assumed for all cases as a fixed percentage of the ship depth. The variation of geometry parameters has been guided by the criterion to cover modifications deemed as plausible during the trade-off process in the preliminary design phase.

In the following, only some selected results are used for the purpose of this paper.

The starting set of data for the investigation is made of 27 cases based on three initial lengths (55 m, 75 m, 95 m); for each length, the breath has been identified by fixing L/B equal to 6, 6.75, 7.5. Then for each breadth, 3 draughts have been found fixing B/T equal to 3.2, 3.5, 3.8. Therefore, 9 cases are obtained for each length, defining a total amount of 27 cases (Figure 2).

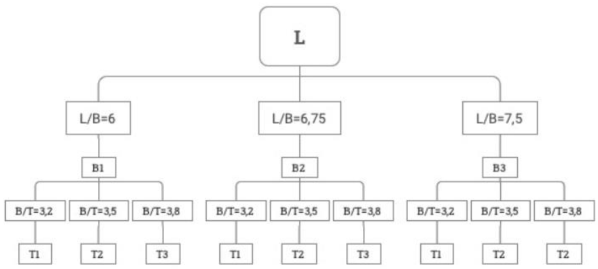

Figure 2: The 27 initial database cases

Further cases have been useful to complete the database for the parametrical identification of the floodable length curve and in particular:

- 12 cases to investigate the variation in F;
- 9 cases to investigate the variation in F/D;

Relevant assumptions for the systematic generation and analysis of data are:

- Permeability of compartments equal to 100% for entire length of the hull;
- the VCG has been assumed as a function of depth (D), i.e. VCG equal to 65% of depth (D);

The margin line has been defined 76 mm lower than the upper surface of the bulkhead deck plating.

In order to compare results, the non-dimensional representation in terms of ship length has been adopted as the favoured option: the Non Dimensional Floodable Length used to present and discuss results in the following figures is defined as the Floodable Length FL divided by the ship length L i.e. FL/L. The Non Dimensional Longitudinal Position is the x coordinate divided by the ship length L i.e. x/L.

3. ANALYSIS OF THE FLOODABLE LENGTH CURVES

For each ship configuration belonging to the selected database, the floodable length curve has been calculated by a stability software. In the following, results are shown, putting in evidence the influence of some selected ship main parameters on the floodable length curve.

3.1 EFFECT OF SHIP BREADTH B

To discuss the effect of ship breadth B on the floodable length curve, it is useful for example observe ship cases 028-029-030 as numbered in Annex.1. They are characterized by the same length (L=55m), depth (D=6.9 m) and draught (T=2.33 m) and three different breadths (B= 9.17-8.15-7.33 m). It is evident as expected that the floodable length curve is not influenced by the breadth B (Figure 3).

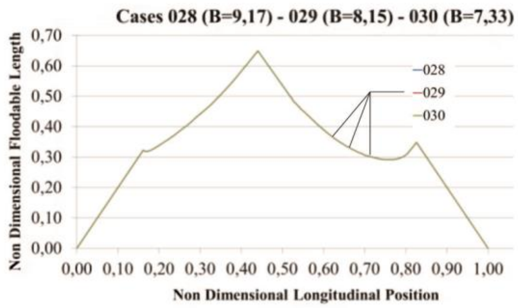

Figure 3: Influence of the ship Breadth

3.2 EFFECT OF SHIP LENGTH L

Again in line with expectations, Figure 4 shows this time the increment of the floodable length curve when the ship length increases. This effect is very evident since the representation of the curves is provided in dimensional mode in metres.

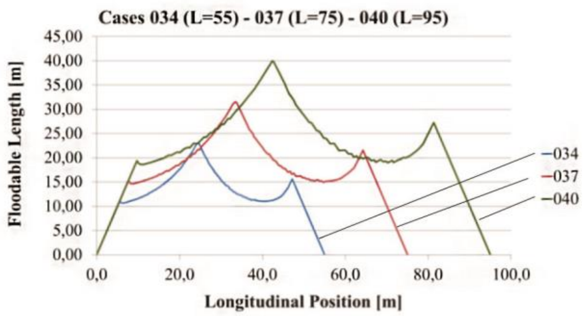

Figure 4: Influence of the ship Length

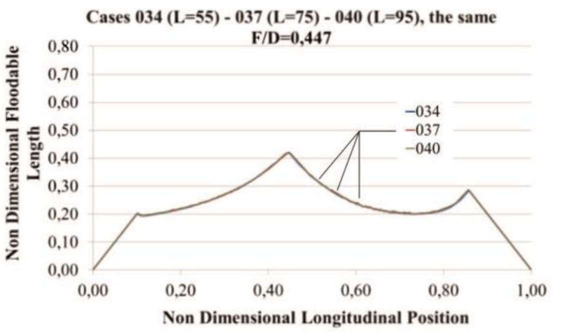

Figure 5: same curves of Figure 4 in non-dimensional mode

In Figure 4 curves are representative of three ships 034-037-040 (see Annex 1), respectively with length of 55 m, 75 m, 95 m and same breath (B= 12.2 m), draught (T=3.81 m) and depth (D=6.9 m).

The very same results, shown this time in the non-dimensional mode (both x-axis and y-axis), coincide in a single curve as can be seen in the Figure 5.

3.3 EFFECT OF SHIP FREEBOARD

After the analysis of effects for lateral and longitudinal ship geometry variations, the floodable length curve has been then investigated in terms of vertical variation. Significant parameters in this case are both the depth D and the draught T. Actually, since the floodable length curve is conceptually and physically related with the reserve of buoyancy, the attention is focused on the difference between them i.e. the freeboard F (i.e. F=D-T).

Several calculations have been carried out in relation with the freeboard F with outcomes observed in terms of maximum value of the floodable length curve (Non Dim. Fl_L@Max) and reported in Figure 6: as expected, the increment of floodable lengths when freeboard increases is evident but, more interesting, it is also evident its linear behaviour.

An important aspect however is that the points on the line are cases with different F, but with same F/D.

On the same graph some results are reported as well for cases with same freeboard e.g. F=3 m (cases from 049 to 060): notwithstanding this common feature, the floodable length can be very different. This has been found to be in relation with different F/D values that have definitely a strong influence on the floodable length curve.

The same effect is evident also for cases 043 and 068 with F= 2.62 m.

For this reason, the investigation proceeded with special attention on the F/D ratio.

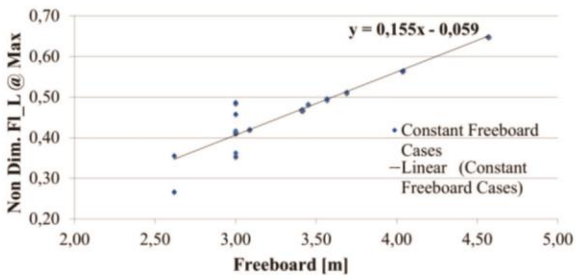

Figure 6: Non dimensional Floodable Length measured at the maximum value (Non Dim. Fl_L@Max) as a function of F

In order to better appreciate the effect of F and F/D, in the next Figure 7 the very same results are reported but putting in evidence the different "families" of data, gathered in terms of freeboard value, as detailed in the relevant legend.

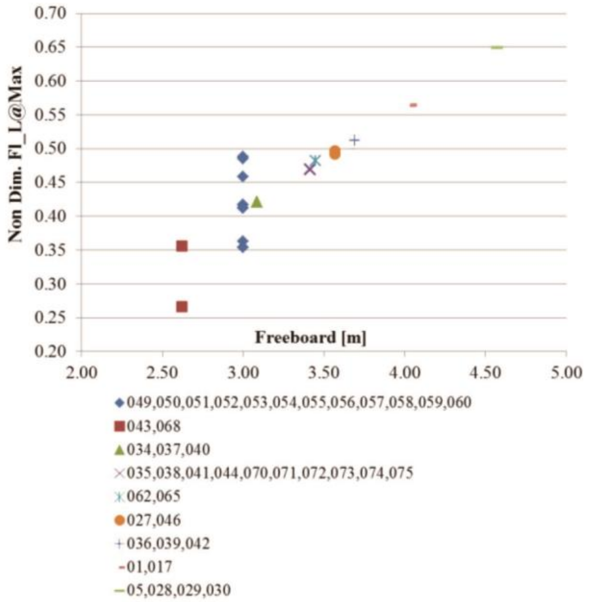

Figure 7: The results reported with evidence of case number

3.4 EFFECT OF F/D

Ships characterized by the same F/D have the same non dimensional floodable length curves. This is evidenced in Figure 8 where curves are represented for cases 060-061-062: they are characterized by same length (L = 75 m), same breath (B= 11.1 m), draught T respectively 3.11 m, 3.45 m, 3.8 m and depth D respectively 6.21 m, 6.9 m, 7.59 m.

The F/D ratio for the three cases is 0.5.

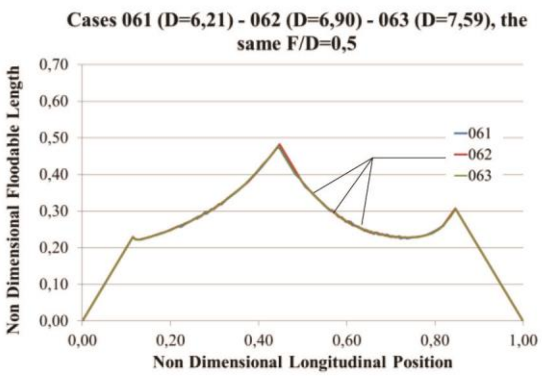

Figure 8: Floodable length curve with the same F/D

Other "families" characterized by constant F/D value are represented in Figure 9 i.e.:

- cases 043-057-060 with F/D=0.38,
- cases 021-066 with F/D=0.4,
- cases 034-037-040 with F/D=0.45,
- cases 011-026-054 with F/D=0.48.

From Figure 9 is evident as expected that the highest set of floodable length curves is the one belonging to the cases with the highest F/D.

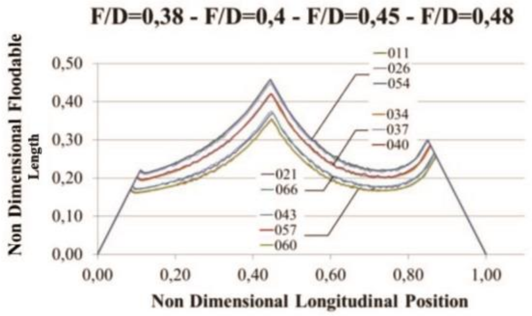

Figure 9: The effect of F/D value

From what above it can be directly quantified how the freeboard F has an effect, as an absolute value, on the floodable length curve.

At the same time it is determined the influence of F/D i.e. the influence of F but this time in relation with the ship depth D.

4. A PROPOSAL FOR A PARAMETRIC EXPRESSION OF THE FLOODABLE LENGTH CURVE

A reliable parametric formulation to define the floodable length curve is needed in order to introduce it into an highly automated process as an efficient criterion for ship subdivision.

For its definition, pre-calculated floodable length curves are investigated.

Three significant points of the floodable length curve have been assumed as representative for each investigated case, in relation with the assumption that the curves have approximatively the same qualitative trend. The three selected points have the following positions (Figure 10):

- longitudinal position at the 30% of the ship length;
- longitudinal position corresponding to the maximum of the floodable length curve;
- longitudinal position at the 70% of the ship length.

These reference points will be useful also later for the validation procedure of the proposed formulations.

As a first step, the non-dimensional values of the floodable length curve at the three reference points have been read and represented as a function of the F/D ratio.

The interpolating lines that approximate such values are represented in Figures 11, 12, 13, together with the relevant analytical linear formulations in terms of F/D.

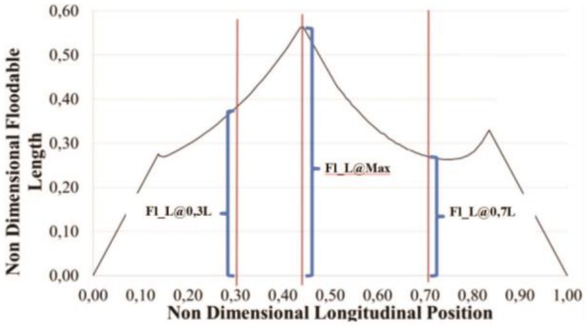

Figure 10: The selected three reference points

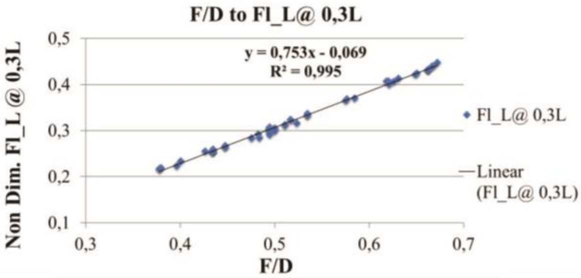

Figure 11: Formulation at 30% of Length

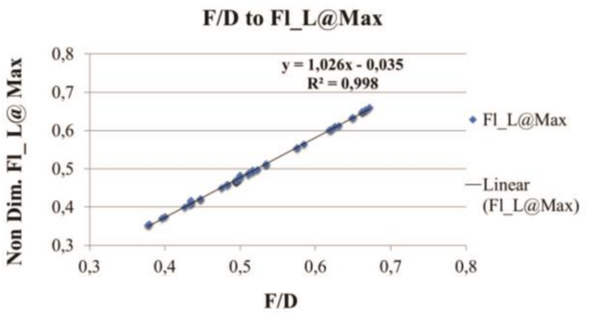

Figure 12: Formulation at maximum of the curve

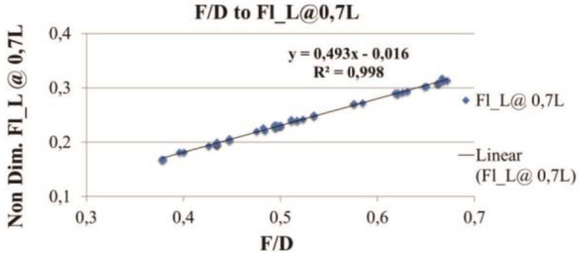

Figure 13: Formulation at 70% of Length

Such formulations have been considered as suitable for the use in an automated ship synthesis model. Other polynomial formulations of higher degree have been considered in the three selected points, but the linear formulation is actually the one that fits better. This evidence is going to be less categorical when the same analysis and formulation are shifted towards the extreme parts of the ship. This topic is going to be discussed again later in this paragraph.

To gain confidence about linear formulation reliability, benchmark analysis has been carried out on existing ships of the same typology, but different from the parent hull.

Five existing ships have been selected: two patrol vessels of nearly 50 m length, other two patrol vessels of nearly 90 m length and, as a possible extension of application domain, a frigate of nearly 145 m length.

The average percentage errors between the estimated values found by the proposed formulations and the actual ones calculated by the ad-hoc floodable length curve software have resulted to be about 1-2% at all the three selected reference points and this has been considered an acceptable error range for the purpose of the application (Annex 2).

Nevertheless, to use the proposed formulations in an automated design process, a methodology enabling the definition of the whole curve starting from the selected reference positions is necessary: a piecewise linear function has been assumed as appropriate to this aim.

To increment the accuracy of the approximated curves, other two points were identified and added at the extremities of the curves, as shown in the Figure 14, evidenced with circles.

The additional two extremities points are estimated with the same methodology already discussed, evaluating the floodable length curve in that specific points thanks to a regression based on the F/D ratio. In this case, points at extremities in terms of longitudinal position are located on a line that starts from X=0, for the stern line, and with an angular coefficient equal to *arctan*(2), (nearly 63.5 degrees). Analogously, the line at bow starts from X=1 with an angular coefficient equal to 180°-*arctan*(2).

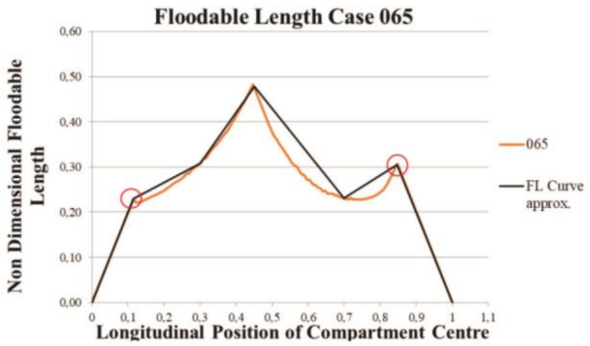

Figure 14: Comparison between the actual curve for case 065 and the estimated one.

In figure 14 the possible level of approximation given by the adoption of the piecewise linear function is evident, especially in the forward part of the curve in this case.

Nevertheless, the general methodology proposed is open for improvement in terms of accuracy because for example the number of significant points along the ship can be reasonably increased, allowing a better agreement between the real curve and the piecewise approximated linear curve.

The formulations for the two added extreme points of the curves have been evaluated as well and they are shown in Figure 15 and Figure 16. Trend lines are again very well defined in relation with F/D but non-linear formulations are more adequate in these cases.

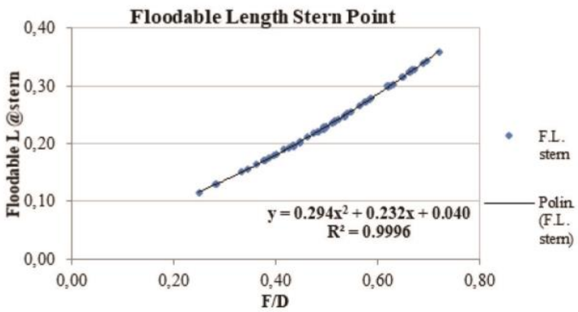

Figure 15: Floodable length curve values @stern as a function of F/D value.

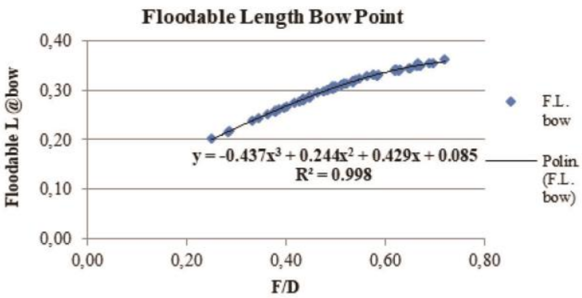

Figure 16: Floodable length curve values @bow as a function of F/D value.

In particular a quadratic formulation is perfectly fitting the values for the point at the afterward part of the ship while the third degree polynomial formulation is the one appropriate for the forward part of the ship.

It appears a superior importance of the F/D parameter on the floodable length value at the extreme parts of the ship. This can be attributed to the different process that characterizes the approaching of the waterline to the margin line, during the flooding: when flooding is in zones amidships the ship increases the draft with an even keel waterline or around that i.e nearly without any trim; when the flooding is supposed at the extreme parts of the ship, the approaching attitude of the waterline to the margin line is the result of both sinkage and trim.

The transverse sections areas moreover are changing more rapidly in the forward and afterward part of the ship, even though in a different way: the change of the section geometry is more evident at the bow that at the stern (Figure 17).

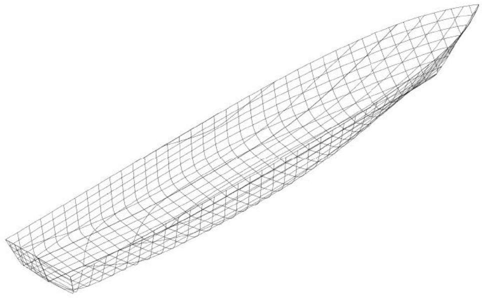

Figure 17: Perspective view of the hull form of the investigated vessel

5. CONCLUSIONS

The ready prediction of the floodable length curve has been investigated in relation with identified ship main characteristics for a dataset of OPV parent vessels.

The final aim was to obtain a simple and reliable parametric formulation of the floodable length curve in relation to the main ship characteristics, usually available during the preliminary design phase.

The paper is motivated by its possible application within an automated generation procedure of feasible ships to be evaluated. For example in trade off analysis or in a design optimization process hundreds of ships are to be generated and it might be too much time consuming to interface with a typical damage stability computational tool.

In the automatic ship generator, the internal subdivision in terms of number and position of transverse watertight bulkhead is necessary to enable a ship survivability assessment at a very preliminary level, necessary in particular for naval vessels.

The parametric formulation of the floodable length curve has been provided in terms of F/D i.e. the ratio between the ship freeboard F=(D-T) and ship depth D.

It is structured into three linear functions defined at the selected significant points (longitudinal position at the 30% of the ship length; longitudinal position corresponding at maximum value of the floodable length curve; longitudinal position at the 70% of the ship length). Such information is then adequate enough to provide a piecewise floodable length curve as acceptable in terms of an approximate representation of the real floodable length curve.

However, the investigation has been limited to a single ship typology, i.e. an Offshore Patrol Vessel (OPV).

Therefore, even though the implemented general approach can be applied in principle to all ship typologies, the specific parametrical formulations derived in this study are applicable only to OPV type ships, even though a possible application to a frigate size ship has been shown to be an acceptable extrapolation.

6. REFERENCES

1. BERTOLOTTO G., GUALENI P., PERRA F., SPANGHERO B. *"The Application of a Ship Synthesis Model (SSM) for the Trade-off Study of Offshore Patrol Vessel"* NAV 2009 Messina, 25-27 November 2009, pp 11-18 Vol. II ISBN 978-88-904394-0-7.
2. BROWN A. J., THOMAS M. (1998) "*Reengineering the Naval Ship Concept Design Process"* ASNE, From Research to Reality in Ship Systems Engineering Symposium. California, USA.
3. IMO (2006) *Resolution Msc.216 (82) – Adoption of Amendments to the International Convention for the Safety of Life at Sea, 1974, as Amended.*
4. JONES A. (2014) *"Design Space Exploration and Optimization Using Modern Ship Design Tools"* Master Thesis of Massachusetts Institute of Technology.
5. KERNS C. M. (2011) *"Naval Ship Design and Synthesis Model Architecture Using a Model-Based Systems Engineering Approach".* Master Thesis of Virginia Polytechnic Institute and State University.
6. NAVSEA Technical Publication (T9070-AF-DPC-010/079-1), *"Design practices and criteria for U.S. Navy surface ship stability and reserve buoyancy",* Naval Sea Systems Command, 2016.
7. PERRA F., GUALENI P., PAOLUCCI M., BRACCO F., RICCOMAGNO, E., LUPI F., DE LUCA M., GUAGNANO A., TADDEI, F., Santic, I., *"Operational Effectiveness, Functions and Naval Tasks: a Multi - Dimensional Environment for the Definition of Naval Units"* NAV 2015 - 18th International Conference On Ships And Shipping Research" Lecco, June 2015 ISBN: 978-88-940557-1-9.
8. SALIO M.P., GUALENI P., PERRA F. *"System Modeling and Performance Assessment for Naval ships Design: an Application for an Offshore Patrol Vessel"* Proceedings of MARTECH 2014, 2nd International Conference on Maritime Technology and Engineering, Lisbon Portugal, October 2014 ISBN 978-1-138-02727-5 277-284.
9. SARCHIN, T.H. and GOLDBERG, L.L., *Stability and Buoyancy Criteria for US Naval Surface Ships,* Transactions SNAME, 1962
10. SAUNDERS S. (2014) – Fighting Ships (2014-2015), Janes Information Group.
11. SNAME (1988) *Principles of Naval Architecture*, (Second Revision), Vol. 1 – Stability and Strength, USA – E. V. LEWIS Editor, ISBN No. 0-9397773-00-7.
12. SOLAS (1974), *"International Convention for the Safety of Life at Sea"*, London (UK), IMO.
13. TUPPER E. *(2014) Introduction to Naval Architecture* (Fifth Edition), Elsevier Ltd., Oxford (UK).

Annex 1: Characteristics of the 70 cases investigated

Case	L	B	D	T	F	Δ	V	L/B	D/B	B/T	D/T	F/D	L/V^(1/3)
	[m]	*[m]*	*[m]*	*[m]*	*[m]*	*[t]*	*[m3]*						
001	55	9,17	6,90	2,86	4,04	595	581	6,00	0,75	3,20	2,41	0,58	6,59
002	55	9,17	6,90	2,62	4,28	514	501	6,00	0,75	3,50	2,63	0,62	6,93
003	55	9,17	6,90	2,41	4,49	446	435	6,00	0,75	3,80	2,86	0,65	7,26
004	55	8,15	6,90	2,55	4,35	436	425	6,75	0,85	3,20	2,71	0,63	7,31
005	55	8,15	6,90	2,33	4,57	374	365	6,75	0,85	3,50	2,96	0,66	7,70
006	55	8,15	6,90	2,14	4,76	323	315	6,75	0,85	3,80	3,22	0,69	8,08
007	55	7,33	6,90	2,29	4,61	326	318	7,50	0,94	3,20	3,01	0,67	8,05
008	55	7,33	6,90	2,10	4,80	281	274	7,50	0,94	3,50	3,29	0,70	8,46
009	55	7,33	6,90	1,93	4,97	243	237	7,50	0,94	3,80	3,58	0,72	8,89
010	75	12,50	6,90	3,91	2,99	1818	1774	6,00	0,55	3,20	1,77	0,43	6,20
011	75	12,50	6,90	3,57	3,33	1582	1543	6,00	0,55	3,50	1,93	0,48	6,49
012	75	12,50	6,90	3,29	3,61	1391	1357	6,00	0,55	3,80	2,10	0,52	6,77
013	75	11,11	6,90	3,47	3,43	1345	1312	6,75	0,62	3,20	1,99	0,50	6,85
014	75	11,11	6,90	3,17	3,73	1164	1136	6,75	0,62	3,50	2,17	0,54	7,19
015	75	11,11	6,90	2,92	3,98	1018	993	6,75	0,62	3,80	2,36	0,58	7,52
016	75	10,00	6,90	3,13	3,78	1027	1002	7,50	0,69	3,20	2,21	0,55	7,50
017	75	10,00	6,90	2,86	4,04	885	864	7,50	0,69	3,50	2,42	0,59	7,88
018	75	10,00	6,90	2,63	4,27	769	750	7,50	0,69	3,80	2,62	0,62	8,26
019	95	15,83	6,90	4,95	1,95	4125	4024	6,00	0,44	3,20	1,39	0,28	5,97
020	95	15,83	6,90	4,52	2,38	3616	3528	6,00	0,44	3,50	1,53	0,34	6,24
021	95	15,83	6,90	4,17	2,73	3211	3133	6,00	0,44	3,80	1,66	0,40	6,49
022	95	14,07	6,90	4,40	2,50	3090	3015	6,75	0,49	3,20	1,57	0,36	6,58
023	95	14,07	6,90	4,02	2,88	2703	2637	6,75	0,49	3,50	1,72	0,42	6,88
024	95	14,07	6,90	3,70	3,20	2383	2325	6,75	0,49	3,80	1,86	0,46	7,17
025	95	12,67	6,90	3,96	2,94	2380	2322	7,50	0,54	3,20	1,74	0,43	7,17
026	95	12,67	6,90	3,62	3,28	2075	2024	7,50	0,54	3,50	1,91	0,48	7,51
027	95	12,67	6,90	3,33	3,57	1820	1776	7,50	0,54	3,80	2,07	0,52	7,85
028	55	9,17	6,90	2,33	4,57	421	410	6,00	0,75	3,93	2,96	0,66	7,40
029	55	8,15	6,90	2,33	4,57	374	365	6,75	0,85	3,50	2,96	0,66	7,70
030	55	7,33	6,90	2,33	4,57	336	328	7,50	0,94	3,15	2,96	0,66	7,98
031	55	9,17	6,90	2,26	4,64	400	390	6,00	0,75	4,05	3,05	0,67	7,53
032	55	8,15	6,90	2,42	4,48	400	390	6,75	0,85	3,36	2,85	0,65	7,53
033	55	7,33	6,90	2,58	4,32	400	390	7,50	0,94	2,84	2,67	0,63	7,53
034	55	12,20	6,90	3,81	3,09	1251	1220	4,51	0,57	3,20	1,81	0,45	5,15
035	55	12,20	6,90	3,49	3,41	1093	1066	4,51	0,57	3,50	1,98	0,49	5,38
036	55	12,20	6,90	3,21	3,69	957	934	4,51	0,57	3,80	2,15	0,53	5,63
037	75	12,20	6,90	3,81	3,09	1706	1664	6,15	0,57	3,20	1,81	0,45	6,33
038	75	12,20	6,90	3,49	3,41	1490	1454	6,15	0,57	3,50	1,98	0,49	6,62
039	75	12,20	6,90	3,21	3,69	1305	1273	6,15	0,57	3,80	2,15	0,53	6,92
040	95	12,20	6,90	3,81	3,09	2161	2108	7,79	0,57	3,20	1,81	0,45	7,41

041	95	12,20	6,90	3,49	3,41	1841	1796	7,79	0,57	3,50	1,98	0,49	7,82
042	95	12,20	6,90	3,21	3,69	1613	1574	7,79	0,57	3,80	2,15	0,53	8,17
Case	**L**	**B**	**D**	**T**	**F**	**Δ**	**V**	**L/B**	**D/B**	**B/T**	**D/T**	**F/D**	**L/V^(1/3)**
	[m]	*[m]*	*[m]*	*[m]*	*[m]*	*[t]*	*[m3]*						
043	55	12,20	6,90	4,28	2,62	1490	1454	4,51	0,57	2,85	1,61	0,38	4,86
044	75	12,20	6,90	3,49	3,41	1490	1454	6,15	0,57	3,50	1,98	0,49	6,62
045	95	12,20	6,90	3,01	3,89	1490	1454	7,79	0,57	4,05	2,29	0,56	8,39
046	75	11,00	6,90	3,33	3,57	1261	1230	6,82	0,63	3,30	2,07	0,52	7,00
047	75	11,00	6,90	2,93	3,97	1025	1000	6,82	0,63	3,75	2,35	0,58	7,50
048	75	11,00	6,90	2,61	4,29	845	824	6,82	0,63	4,21	2,64	0,62	8,00
049	55	9,17	6,90	3,90	3,00	1261	1230	6,00	0,75	2,35	1,77	0,43	5,13
050	75	11,11	6,90	3,90	3,00	1025	1000	6,75	0,62	2,85	1,77	0,43	7,50
051	95	12,67	6,90	3,90	3,00	845	824	7,50	0,54	3,25	1,77	0,43	10,13
052	75	12,50	7,75	4,75	3,00	2296	2240	6,00	0,62	2,63	1,63	0,39	5,73
053	75	11,11	6,90	3,90	3,00	1610	1571	6,75	0,62	2,85	1,77	0,43	6,45
054	75	10,00	6,20	3,20	3,00	1133	1105	7,50	0,62	3,13	1,94	0,48	7,25
055	75	12,20	5,87	2,87	3,00	1202	1173	6,15	0,48	4,25	2,05	0,51	7,11
056	75	12,20	6,90	3,90	3,00	1768	1725	6,15	0,57	3,13	1,77	0,43	6,25
057	75	12,20	7,94	4,94	3,00	2347	2290	6,15	0,65	2,47	1,61	0,38	5,69
058	75	12,20	5,87	2,87	3,00	1202	1173	6,15	0,48	4,25	2,05	0,51	7,11
059	75	12,20	6,90	3,90	3,00	1768	1725	6,15	0,57	3,13	1,77	0,43	6,25
060	75	12,20	7,94	4,94	3,00	2347	2290	6,15	0,65	2,47	1,61	0,38	5,69
061	75	11,11	6,21	3,11	3,11	1202	1173	6,75	0,56	3,57	2,00	0,50	7,11
062	75	11,11	6,90	3,45	3,45	1333	1300	6,75	0,62	3,22	2,00	0,50	6,87
063	75	11,11	7,59	3,80	3,80	1496	1460	6,75	0,68	2,92	2,00	0,50	6,61
064	75	11,11	6,21	2,07	4,14	612	597	6,75	0,56	5,37	3,00	0,67	8,91
065	75	11,11	6,90	3,45	3,45	1333	1300	6,75	0,62	3,22	2,00	0,50	6,87
066	75	11,11	7,59	4,55	3,04	1934	1887	6,75	0,68	2,44	1,67	0,40	6,07
067	75	11,11	8,35	5,57	2,78	2490	2429	6,75	0,75	1,99	1,50	0,33	5,58
068	75	11,11	9,18	6,56	2,62	3024	2950	6,75	0,83	1,69	1,40	0,29	5,23
069	75	11,11	10,10	7,58	2,52	3569	3482	6,75	0,91	1,47	1,33	0,25	4,95
070	75	12,20	6,90	3,49	3,41	1490	1454	6,15	0,57	3,50	1,98	0,49	6,62

Annex 1: Characteristics of the 70 cases investigated

Annex 2: Difference in percentage between estimated (by parametric formulation) and calculated Floodable Length (Fl_L)

Case	*Err Fl_L@0.3L*	*Err Fl_L@Max*	*Err Fl_L@0.7L*
Patrol vessel≈50_01	0,1%	0,1%	0,5%
Patrol vessel≈50_02	-0,1%	1,1%	0,5%
Patrol vessel≈80_01	-0,6%	0,1%	-0,8%
Patrol vessel≈80_02	-0,3%	-0,4%	-1,1%
Frigate vessel	-0.8%	0.7%	-0.8%