Study of Stability on Water for a Special Amphibious Autovehicle

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Abstract. As the automotive industry is in continuos change, moving from a mechanical to a software-intensive industry, an essential part of the development and research process is represented by the computerized modelling and simulation since, this mechanism, provides prediction on how a vehicle will behave in real life situations. For studying and experimentally testing special purpose amphibious vehicles, it is preferable to use software programs, in order to reduce costs and to have a proper look on how a vehicle will work in reality and to avoid the risks of carrying out tests in open water. The scientific aim of this paper is to study the stability of an amphibious vehicle with special purpose through the means of computer-aided-design (CAD) applications software. First of all, a lot of measurement had to be done in order to design 2D sketches, which eventually, will lead to a 3D model of a chosen amphibious vehicle with special purpose, which resembles the one used in reality. Then, in order to study stability, the model was imported to a naval-friendly software and the curves of stability were obtained. In addition, the flooding points of the amphibious vehicle were set. Furthermore, different loading cases were taken into consideration for an equilibrium analysis. Lastly, the process of water entry/exit of the amphibious vehicle was studied using Bonjean Scale.

Keywords: Amphibious vehicle · Stability · Simulation · Turbulence 3D modelling

1 Introduction

An amphibious vehicle must provide adequate buoyancy to support itself and its contents or working loads. It is supposed that the buoyancy to be provided in a way that will allow floatation in the proper attitude, or trim, and remain upright. This brings into discussion, the problems of gravitational stability and trims [1]. To study stability through the means of CAD applications software, a 3D model of a special purpose amphibious vehicle will be built by using 2D sketches. Also, determining the position of the center of gravity is essential to studying stability of an amphibious vehicle. It may be either calculated or determined experimentally using the inclining experiment, but in this paper, the position of the center of gravity will be established by a weight estimate,

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which is a summation of the estimated weights and moments of all the various items that equip the amphibious vehicle [1]. As a further matter, different loading cases will be defined in order to analyze the equilibrium of the amphibious vehicle. If a floating body, initially at equilibrium, is disturbed by an external moment, there will be a change in its angular attitude. If upon removal of the external moment, the body tends to return to its original position and it is said to have been in stable equilibrium and to have positive stability. Then, the resulted 3D model of the amphibious vehicle will be imported for simulations in a software program, generally used by naval engineers. As a starting point for a stability booklet, stability criteria will be taken into consideration.

2 Objectives

By taking into consideration the fact the real life the experimental researches of the military vehicles require big amounts of money, the main purpose of this paper is to provide an alternative, through the means of computerized simulations of different cases of working. Specifically, the stability will be studied, as it plays a major part for an amphibious.

3 Methodology

In order to validate the results and for means of comparison with data obtained in real life experiments, the amphibious vehicle chosen for modelling and simulations was an armored personnel carrier (APC) (the vehicle is presented in Fig. 1), which is a fully amphibious used in the Romanian Army. Even though, the vehicle has come a long way since its establishment in the army, few studies have been conducted to evaluate its stability on water by using computerized simulations.

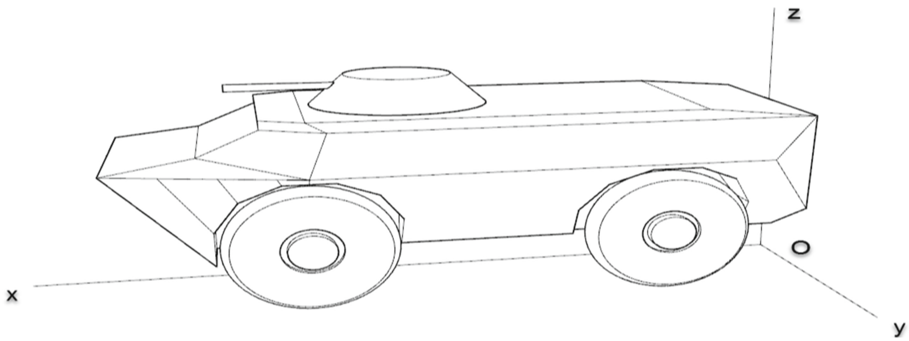

Fig. 1. Romanian APC

The first step of the process was to choose from a wide range of CAD software, the one that would accurately represent the complex hull surfaces of the chosen amphibious vehicle. It has to be mentioned, that in order to achieve this goal, a lot of precise measurement had to be realized, for that the model of the vehicle to be proper. Thus, the appointed software for the modelling of the amphibious vehicle was Rhinoceros 3D. Rhinoceros geometry is based on the NURBS (non-uniform rational basis spline) mathematical model, which focuses on producing mathematically precise representation of curves and freeform surfaces in computer graphics (as opposed to polygon mesh-based applications). Moreover, the software offers compatibility with other software as it supports over 3D CAD file formats for importing and exporting. This feature of the software was used to import 2D Autocad sketches (the sketches are shown in Fig. 2) of the APC into Rhinoceros as a starting point of the designing of the hull.

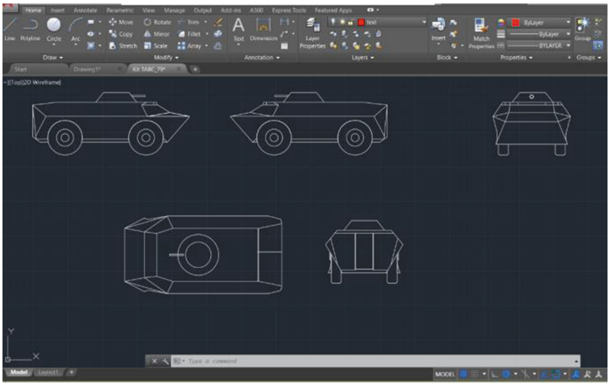

Fig. 2. 2D Autocad sketches of the APC

One of the main reasons of choosing Rhinoceros 3D for modelling was the fact that it offers the possibility of creating complex surfaces, as those of the hull of the APC. All surface creation commands result in the same object: a NURBS surface [5]. Rhinoceros 3D has many tools for constructing surfaces directly or from existing curves. The result of the modelling can be observed in Fig. 3.

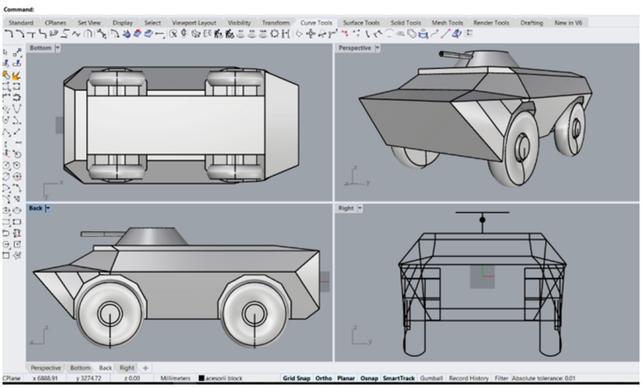

Fig. 3. Model of APC in Rhinoceros 3D

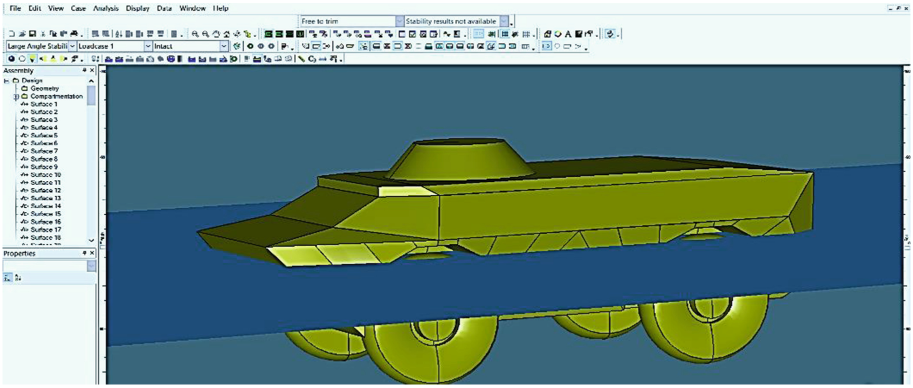

Fig. 4. The model of APC in Maxsurf

Yet, for the stability to be studied, the model was not sufficient. Maxsurf was picked out as the software for the simulations and for the calculations to be performed. The Maxsurf Stability module provides fast, graphical and interactive calculation of intact and damaged stability and strength for the model. Once a design has been created using the Modeler module or another compatible software, its stability and strength characteristics can be assessed using the Stability analysis module. That provides a range of powerful analysis capabilities to handle all types of stability and strength calculations: large angle, longitudinal strength, floodable length, downflooding points and verification with built-in comprehensive libraries of stability criteria from all major regulatory bodies. In Fig. 4 [2], it is presented the model of APC with a defined waterline, after the transfer from Rhinoceros 3D into Maxsurf.

1	Draft Amidships m	1,425
2	Displacement t	10,19
3	Heel deg	0,2
4	Draft at FP m	1,380
5	Draft at AP m	1,470
6	Draft at LCF m	1,427
7	Trim (+ve by stern) m	0,090
8	WL Length m	5,550
9	Beam max extents on WL m	2,730
10	Wetted Area m^2	36,364
11	Waterpl. Area m^2	13,558
12	Prismatic coeff. (Cp)	0,833
13	Block coeff. (Cb)	0,453
14	Max Sect. area coeff. (Cm)	0,719
15	Waterpl. area coeff. (Cwp)	0,895
16	LCB from zero pt. (+ve fwd) m	-0,228
17	LCF from zero pt. (+ve fwd) m	-0,130
18	KB m	0,979
19	KG fluid m	1,314
20	BMt m	0,736
21	BML m	3,371
22	GMt corrected m	0,401
23	GML m	3,035
24	KMt m	1,715
25	KML m	4,349
26	Immersion (TPc) tonne/cm	0,139
27	MTc tonne.m	0,055
28	RM at 1deg = GMt.Disp.sin(1) tonne.	0,071
29	Max deck inclination deg	0,9321
30	Trim angle (+ve by stern) deg	0,9142

a)

1	Draft Amidships m	1,374
2	Displacement t	9,501
3	Heel deg	0,0
4	Draft at FP m	1,376
5	Draft at AP m	1,373
6	Draft at LCF m	1,374
7	Trim (+ve by stern) m	-0,003
8	WL Length m	5,541
9	Beam max extents on WL m	2,644
10	Wetted Area m^2	34,803
11	Waterpl. Area m^2	12,433
12	Prismatic coeff. (Cp)	0,803
13	Block coeff. (Cb)	0,460
14	Max Sect. area coeff. (Cm)	1,076
15	Waterpl. area coeff. (Cwp)	0,849
16	LCB from zero pt. (+ve fwd) m	-0,180
17	LCF from zero pt. (+ve fwd) m	-0,109
18	KB m	0,947
19	KG fluid m	1,312
20	BMt m	0,644
21	BML m	3,364
22	GMt corrected m	0,280
23	GML m	2,999
24	KMt m	1,592
25	KML m	4,311
26	Immersion (TPc) tonne/cm	0,127
27	MTc tonne.m	0,050
28	RM at 1deg = GMt.Disp.sin(1) tonne.	0,046
29	Max deck inclination deg	0,0271
30	Trim angle (+ve by stern) deg	-0,027

b)

Fig. 5. Corresponding results for the first loading case (a), respectively the second loading case (b)

4 Results

The fundamental concept behind the understanding of intact stability of a floating body is that of equilibrium [4]. The intact stability deals with the stability of a surface ship, when the intactness of its hull is maintained, and no compartment or watertight tank is damaged or freely flooded by seawater. The Equilibrium module of Maxsurf offers the possibility to determine the draft, heel and trim of the hull as a result of the loads applied in the Loadcase window. In this paper, the analysis will be carried out in flat water [3]. Two loading cases will be defined: first (Table 1), for the vehicle with all crew members and, full tanks and with their arrangement, ready for battle.

Table 1. Loading case for ready to battle.

	Item Name	Quantity	Unit Mass tonne	Total Mass tonne	Unit Volume m^3	Total Volume m^3	Long. Arm m	Trans. Arm m	Vert. Arm m	Total FSM tonne.m	FSM Type
1	Lightship	1	9,141	9,141			-0,185	0,000	0,000	0,000	User Spe
2	Driver	1	0,110	0,110			1,600	-0,400	-0,100	0,000	User Spe
3	Commander	1	0,110	0,110			1,600	0,400	-0,100	0,000	User Spe
4	Officer	1	0,110	0,110			0,650	-0,300	0,450	0,000	User Spe
5	Crew member 1	1	0,110	0,110			-0,200	0,500	-0,100	0,000	User Spe
6	Crew member 2	1	0,110	0,110			-0,200	-0,500	-0,100	0,000	User Spe
7	Crew member 3	1	0,110	0,110			-0,600	0,200	-0,100	0,000	User Spe
8	Crew member 4	1	0,110	0,110			-1,200	0,200	-0,100	0,000	User Spe
9	rezervor 1	100%	0,141	0,141	0,168	0,168	-2,680	0,450	-0,050	0,000	Maximum
10	rezervor 2	100%	0,141	0,141	0,168	0,168	-2,680	-0,450	-0,050	0,000	Maximum
11	**Total Loadcase**			**10,193**	**0,335**	**0,335**	**-0,222**	**0,001**	**-0,003**	**0,000**	
12	**FS correction**								**0,000**		
13	**VCG fluid**								**-0,003**		

The second loading case (Table 2) is defined with only the driver, the commander of the amphibian and with half of the tanks.

Table 2. The second loading case.

	Item Name	Quantity	Unit Mass tonne	Total Mass tonne	Unit Volume m^3	Total Volume m^3	Long. Arm m	Trans. Arm m	Vert. Arm m	Total FSM tonne.m	FSM Type
1	Lightship	1	9,141	9,141			-0,185	0,000	0,000	0,000	User Spe
2	Driver	1	0,110	0,110			1,600	-0,400	-0,100	0,000	User Spe
3	Commander	1	0,110	0,110			1,600	0,400	-0,100	0,000	User Spe
4	rezervor 1	50%	0,141	0,070	0,168	0,084	-2,680		-0,250	0,007	Maximum
5	rezervor 2	50%	0,141	0,070	0,168	0,084	-2,680	-0,450	-0,250	0,007	Maximum
6	**Total Loadcase**			**9,502**	**0,335**	**0,168**	**-0,181**	**0,000**	**-0,006**	**0,014**	
7	**FS correction**								**0,002**		
8	**VCG fluid**								**-0,005**		

The corresponding results in the equilibrium module obtained are presented in Fig. 5a, b respectively.

In case of the amphibious vehicles, an unstable equilibrium can exist when the KG > KM, i.e. the centre of gravity is above the metacentre (negative GM_t) [4]. In real case a ship in unstable equilibrium will roll from the upright unstable equilibrium position to a position of stable equilibrium and assume an angle of heel. Since Maxsurf Stability starts the equilibrium analysis in upright position [6], it has no way of determining whether the equilibrium is stable or unstable. This means that unstable equilibrium may be found instead of the stable equilibrium. Therefore it is recommend checking the value of GM_t after doing an equilibrium analysis or use the Large Angle Stability analysis of Maxsurf and look at the slope of the GZ curve through the equilibrium heel angle.

For the analysis of stability [4, 6], using the Large Angle Stability module of Maxsurf, displacement and centre of gravity are specified in the load case. A range of heel angles at which the vehicle will incline are specified and Maxsurf Stability calculates the righting lever and other hydrostatic data at each of these heel angles by balancing the load case displacement against the hull buoyancy and, if the model is free-to-trim, the centre of gravity against the centre of buoyancy such that the trimming moment is zero. In Fig. 6, it is being shown the setting up of the range of heel angles of the amphibious that will be analyzed.

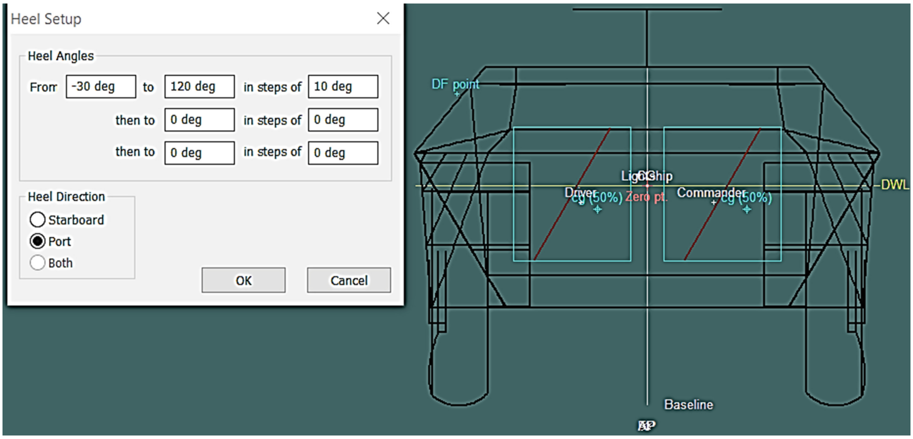

Fig. 6. Choosing the range of heel angles for the simulation

The key output value is GZ (or righting lever), the horizontal distance between the centers of gravity and buoyancy. A graph of these values at the various heel angles forms a GZ curve. More information is often overlaid on the GZ curve, including upright GM, curves for wind heeling and passenger crowding levers and the angle of the first down-flooding point. The position of the downflooding was set where the air filter of APC is located in reality. The graphic of the GZ curve found in the *Graph Window* for the stability simulation can be observed in Fig. 7. A number of other graphs may be selected from the pull-down list in the graph window, such as the curve of areas, curves of form or dynamic stability (GZ area). It can be noticed that the maximum heel angle at which the amphibious is stable is approximately 85°, but taking the downflooding point into consideration, the heel angle is reduced to 21.2°.

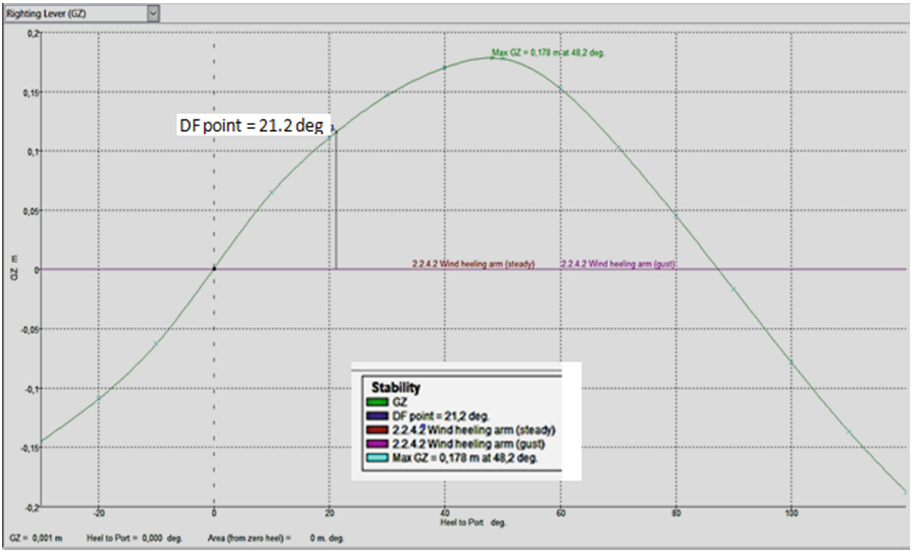

Fig. 7. Graph of the righting lever of stability

When discussing stability, it has to be mentioned that any amphibious can navigate if it fulfills conditions that are structured in the stability criteria. In this simulation (Fig. 8), the vehicle passes one of the stability criteria for pontoons.

	Code	Criteria	Value	Units	Actual	Status	Margin %
1	2.2 Pontoons	2.2.4.1 GZ area: to Max GZ				Pass	
2		*from the greater of*					
3		angle of equilibrium	-0,2	deg	-0,2		
4		*to the lesser of*					
5		angle of max. GZ	48,2	deg	48,2		
6		**shall be greater than (>)**	4,5837	m.deg	5,5626	Pass	+21,36
7							

Fig. 8. The criteria results window of Maxsurf

5 Conclusions

When it comes to studying stability of a special purpose amphibious vehicle, with efficiency, effectiveness, minimal costs and with complete safety, can be used the computerized modeling and simulation software applications. In this paper, accurate tests have been conducted on a model of a vehicle which replicates reality. The statically stability curve which is part of any stability booklet was determined, also, taking notice of the downflooding points of the amphibious. Moreover, through the means of computer-aided software applications, an equilibrium analysis has been done, considering different loading cases. Additionally, the results were evaluated by using criteria legislated by the International Maritime Organization.

To conclude, the methodology practiced in this paper for studying stability, was used for a certain type of special purpose amphibious vehicle, but it can be as well applied to any type of amphibious.

References

1. Moore, C.S.: Intact Stability, 1st edn. The Society of Naval Architects and Engineers, Jersey City (2010)
2. ***, Maxsurf Windows Version 12 User Manual Page
3. Marineinsight Homepage. https://www.marineinsight.com/naval-architecture/ship-stability-understanding-curves-static-stability/
4. Marinescu, M.: Teoria, calculul şi construcţia transportoarelor blindate, vol. 2. Academiei Tehnice Militare, Bucureşti (2006). ISBN: 9736401146, ISBN: 9789736401145
5. ***, Rhinoceros 3D, software documentation
6. ***, Max Surf, software help documentation