ANALYSIS OF THE PROCESS OF WATER ENTRY OF AN AMPHIBIOUS VEHICLE

ZBIGNIEW BURCIU[1], MAREK KRASKOWSKI[2], MATEUSZ GERIGK[3]

Gdynia Maritime University, Ship Design and Research Centre, Context Office

Summary

The paper presents a method of computational and experimental analysis of the process of water entry of an amphibious vehicle. The computational method is based on the Reynolds Averaged Navier-Stokes Equations (RANSE) solver and the experiment was carried out in the towing tank at Ship Design and Research Centre S.A. with the use of a scale model. The analysis was focused on the safety of water entry, i.e. the maximum pitch and roll angles, the maximum acceleration, as well as the occurrence and degree of flooding of bonnet and windscreen. Both the computations and the experiment have revealed that in the case of free water entry, i.e. without braking, the water covers the windscreen even at a moderate slope of the beach (10°); however, if braking of the wheels during the water entry process were possible, the flooding of the bonnet and windscreen could be avoided even at a steep slope (30°).

Keywords: amphibious vehicle, water entry, model tests, CFD.

1. Introduction

The amphibian as a vehicle that can operate both on water and on land must meet stringent requirements laid down for the vehicles that are to be driven on public roads. It must also have some features that would ensure appropriate vehicle behaviour when afloat; however, the capability of crossing the boundary between the land and water environments is of considerable importance as well. One of the problems is the behaviour of the vehicle when entering the water and coming out onto the land.

This paper presents selected results of numerical simulations and physical model research on the process of water entry of a vehicle named ASD (which stands for Amphibious Command System), being now built within a research and development project No. 0008R/T00/2010/11 entitled *Mobile system for command, observation, detection and communication.* The research work described herein covers the impact of the beach slope angle and the initial vehicle speed.

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[1] Gdynia Maritime University, Faculty of Navigation, Department of Ship's Operation, 3 Al. Jana Pawła II Street, 81-325 Gdynia, e-mail: zbj@am.gdynia.pl

[2] Ship Design and Research Centre (CTO S.A.), Ship Hydromechanics Division, 65 Szczecińska Street, 80-392 Gdynia, e-mail: marek.kraskowski@cto.gda.pl

[3] Context Office Mateusz Gerigk (architectonic office), 17/6 Słupecka Street, 81-316 Gdynia

The computations were aimed at the assessment of safety of the water entry process, i.e. the degree of flooding of the vehicle when entering the water, the accelerations encountered, and the instantaneous trim angles.

2. Simulation tests on the water entry of the vehicle model

The research on the processes of entering the water and coming out onto the land requires that a numerical analysis should be carried out at first. When the vehicle body shape and the mass distribution are preliminarily defined to ensure adequate buoyancy and road performance characteristics of the vehicle, numerical simulations are carried out to introduce corrections to the body shape so that the water entry process is safe in respect of the possible flooding of the vehicle as well as the actual accelerations and instantaneous trim angles to be expected. The general view and overall dimensions of the vehicle shape have been shown in Fig. 1.

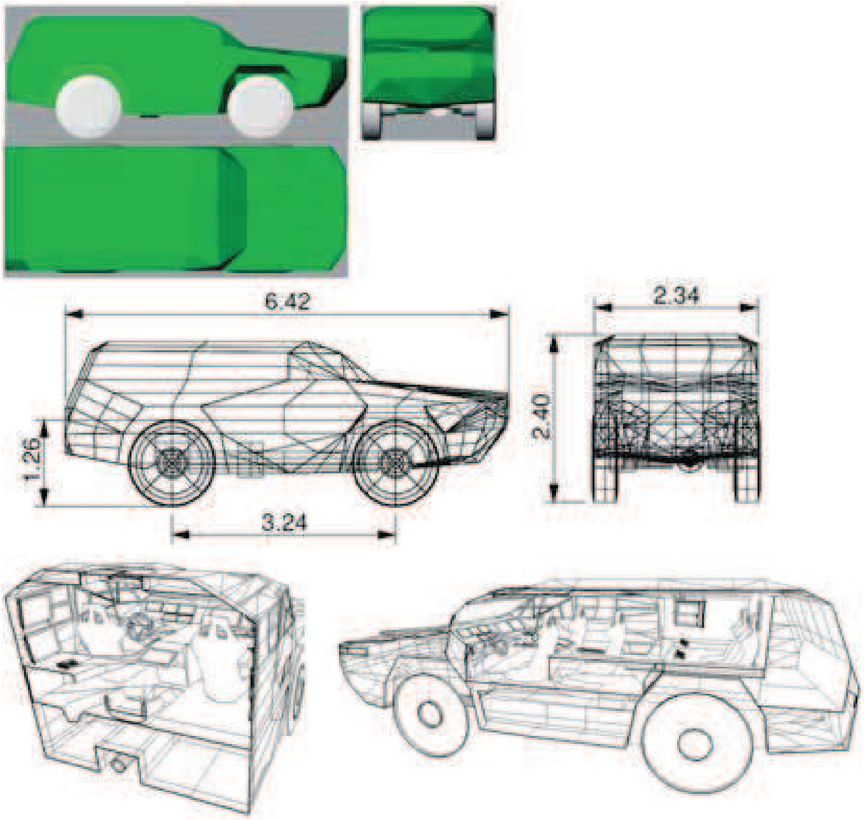

Fig. 1. General view, cross-section, and overall dimensions of the vehicle shape

The vehicle shape was defined during the process of optimising it to obtain the best possible floating performance [1]. The digital simulations were carried out at the Ship Hydromechanics Division of the Ship Design and Research Centre (CTO S.A.) with the use of a STAR CCM+ system, where the Reynolds Averaged Navier-Stokes Equations (RANSE) solver and the finite volume method (FVM) were employed [3].

The water entry manoeuvre may be described as a process where the vehicle on its wheels enters a water reservoir from land sloped at a certain angle. The vehicle behaviour at the initial stage of the motion depends on the water entry speed and the hydrodynamic properties of the vehicle shape. Four combinations of vehicle speed V and slope angle α of the ground (bottom of the water reservoir) were taken into account at the computations:

- $\alpha = 10°$, $v = 0\ \mathrm{ms}^{-1}$,
- $\alpha = 10°$, $v = 1\ \mathrm{ms}^{-1}$,
- $\alpha = 20°$, $v = 0\ \mathrm{ms}^{-1}$,
- $\alpha = 20°$, $v = 1\ \mathrm{ms}^{-1}$.

The vehicle dimensions made it possible to carry out full-scale computations. The simulations were based on the main assumption made that the vehicle freely entered the water, i.e. with neither the vehicle wheels being driven nor brakes being applied to them and with the propeller being inactive. The process was considered to begin when the front vehicle wheels touched the water surface. Many other assumptions were simultaneously made, which were related to such factors as the ground (the impact of the ground on water flows), the wheel movement when the vehicle got afloat, or the water reservoir size.

An analysis of the vehicle motion during the water entry process made it possible to ascertain the following:

- Time history of the trim angle (the trim angle is zero when the vehicle is on a horizontal surface; the trim angle is positive when the vehicle is trimmed by the head);
- Time history of the displacement of the centre of mass in the coordinate system adopted (Fig. 2);

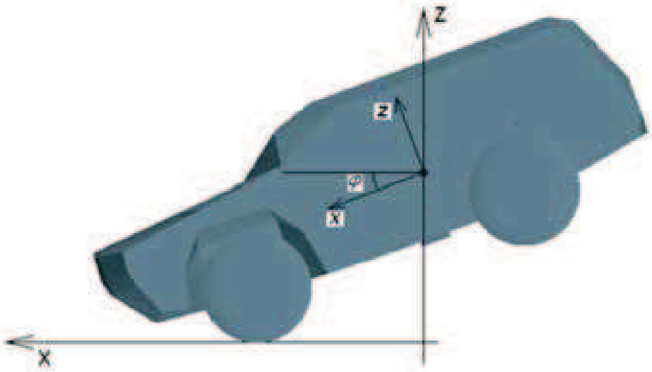

Fig. 2. Coordinate system adopted [1, 4]

- Time histories of the individual components of velocity of the centre of mass;
- Time histories of the acceleration values.

The course of the water entry process represented by the digital simulation has been shown in Fig. 3. At the test presented in the illustration, the water entry was simulated for a reservoir bottom slope angle of α = 20° and an initial vehicle speed of V = 1 ms^{-1}.

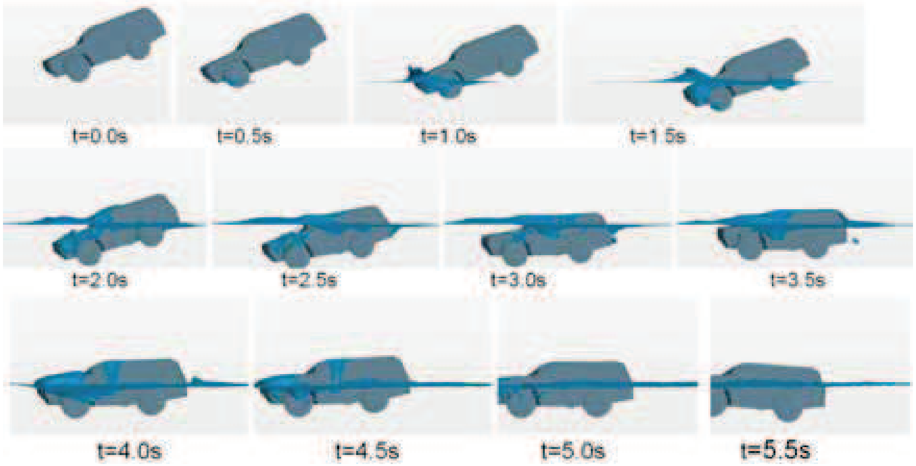

Fig. 3. Visualisation of the water entry process [1, 4]

The trim angle vs. time curves for all the cases under consideration have been shown in Fig. 4. During the water entry at the 10° slope angle, the bonnet and windscreen became flooded, according to the analysis; when the slope angle was 20°, complete submersion of the front part of the vehicle took place (Fig. 3).

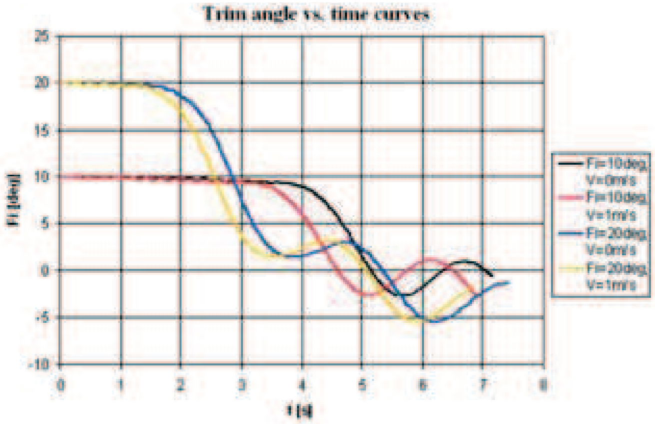

Fig. 4. Trim angle vs. time curves for all the cases under consideration [1, 4]

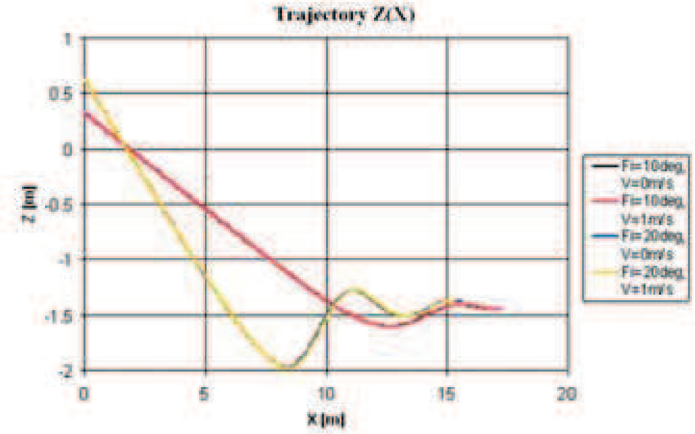

Fig. 5. Trajectory of the vehicle centre of mass for all the cases under consideration [1, 4]

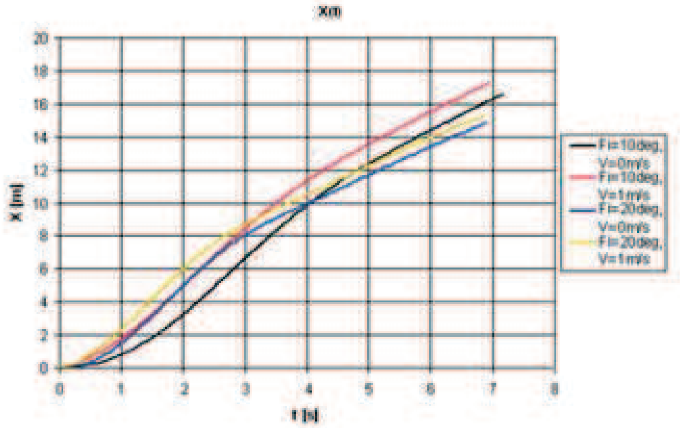

Fig. 6. Horizontal displacement of the vehicle centre of mass vs. time curves for all the cases under consideration [1, 4]

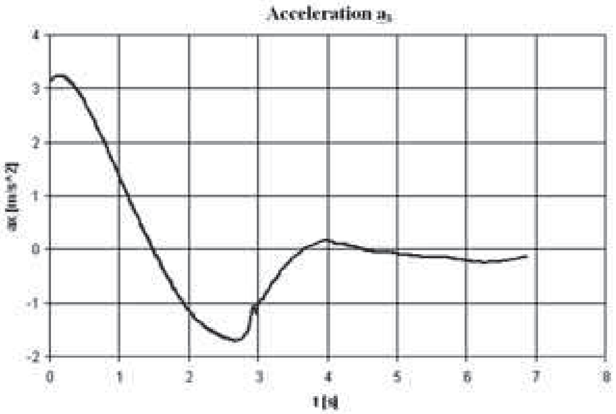

Fig. 7. Acceleration a_x of the vehicle centre of mass vs. time curve; slope angle 20°, initial speed 1 m/s [1, 4]

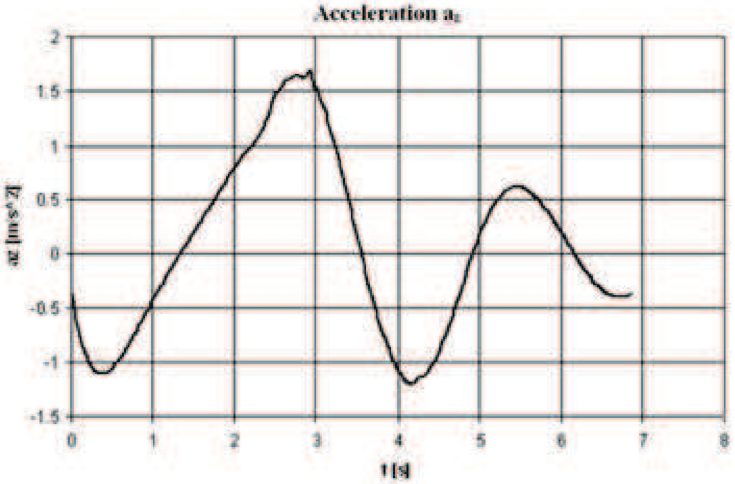

Fig. 8. Acceleration a_z of the vehicle centre of mass vs. time curve; slope angle 20°, initial speed 1 m/s [1, 4]

The analysis of the process of water entry of the vehicle provided grounds for making a statement that the changes in the initial speed within the range from 0 to 1 m/s had an insignificant impact on the course of the vehicle motion with time and practically no impact on the trajectory of the vehicle centre of mass (Fig. 5). It was also found that the rate of losing speed during the water entry process was higher for the slope angle of 20° than that for the slope angle of 10° (Figs. 5 and 6). An important finding from the ride comfort point of view is the fact that the vehicle accelerations during the water entry were relatively low, of the order of 3 m/s^2 (0.3 g) in both directions in the extreme case (Figs. 7 and 8).

Following the numerical analysis, the vehicle shape was corrected [1] and model tests were carried out [4] in the model basin at the Ship Hydromechanics Division of the Ship Design and Research Centre (CTO S.A.) on a test stand diagrammatically shown in Fig. 9. The motion parameters measured (Fig. 10) were the acceleration components a_x and a_z and the angle between the vehicle and the horizontal plane because they are most important for the safety of the vehicle crew and the vehicle itself.

For the test purposes, an adjustable ramp was made, supported in a pivot bearing at point A (Fig. 9); the pivot axis was situated at the intersection of the water level with the plane on which the vehicle moved.

The tests were carried out as follows:

- The ramp angle (slope) was adjusted by changing the height of point B (Fig. 9).
- The vehicle model was manually held at a preset distance (referred to herein as the run-up distance) from the water level. The vehicle was released a short while after the recording of the vehicle motion was started (the recording included measuring of the horizontal and vertical acceleration, measuring of the vehicle angle in relation to the horizontal plane, and filming with a rate of 50 frames per second).

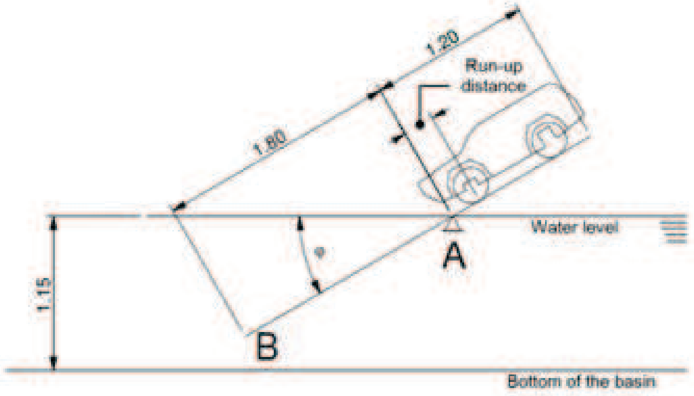

Fig. 9. Schematic diagram of the test stand [1, 4]

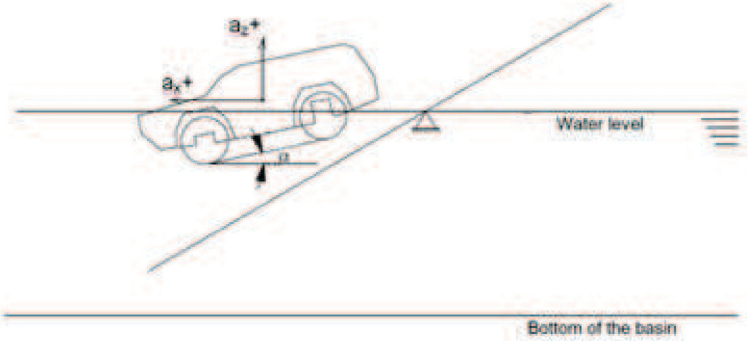

Fig. 10. The quantities measured [1, 4]

- The vehicle freely entered the water (i.e. no additional braking forces were applied apart from the rolling resistance and the friction occurring in the model axle bearings).

Five values of the slope angle α were applied, i.e. 10°, 15°, 20°, 25°, and 30°. For each of the slope angle, water entry tests were carried out with four run-up distance values, i.e. 5 cm, 15 cm, 25 cm, and 35 cm.

Hence, the ranges of the initial water entry speeds 0 ÷ V were different for different values of the slope angle α. The method of controlling the initial vehicle speed by applying preset run-up distance values identical for all the slope angle values was chosen for the following reasons:

- The wide range of run-up distance values made it possible to obtain a wide range of the initial water entry speeds of the vehicle, sufficient for the evaluation of the impact of the speed on the course of the water entry process.
- It would be very troublesome to select the appropriate run-up distance so as to obtain a required value of the initial speed.

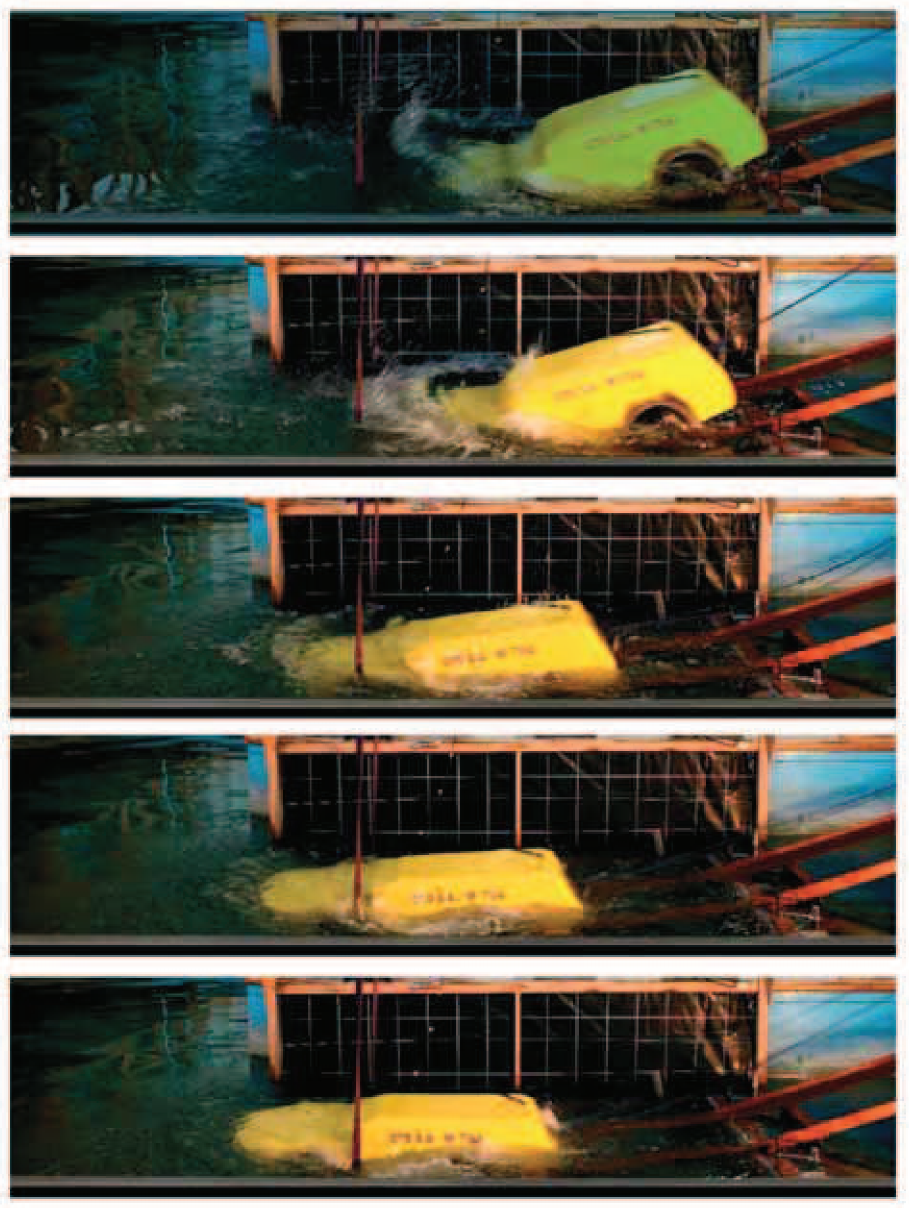

Fig. 11. Submersion of the vehicle during the water entry process; slope angle 20°, initial speed V_0 = 3.35 m/s [1, 4]

Fig. 11 shows successive stages of the water entry process as recorded during the tests; at this specific test, the slope angle and the initial vehicle speed were α = 20° and V_0 = 3.35 m/s, respectively.

3. Conclusions

In result of the model tests carried out, the following conclusions could be formulated:

- At ground slope angles of 15° ÷ 30°, both the bonnet and windscreen were flooded. Only at the least slope angle taken into account at this research work, i.e. 10°, the windscreen was not flooded while the bonnet was partly or totally covered with water in such a case as well. It was observed, however, that if the adhesion of the rear axle wheels were sufficient to reduce the water entry speed of the vehicle almost to zero then it would be possible to drive the vehicle into the water with avoiding the flooding of the bonnet and windows in the whole range of the slope angles under consideration.
- At a ground slope angle of 30°, the vehicle submerged almost completely.
- The water entry speed was observed to have a small impact on changes in the trim angle and the vehicle acceleration values.
- The backward dip angle (i.e. the trim astern immediately following the water entry process) did not exceed eight degrees in relation to the horizontal plane, i.e. about five degrees in relation to the static trim angle of the vehicle.
- The overloads and load reductions occurring at the water entry process did not exceed 0.4 g; so, they may be considered quite small.
- No problems with the lateral vehicle stability were observed to occur during the water entry process.

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