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Numerical analysis of MOB manoeuvres in regard to a body suffering from hypothermia

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Abstract

The following paper's aim is to provide a numerical analysis of well-known man overboard (MOB) manoeuvres undertaken by vessels' masters' in critical situations, when a passenger or crew member falls out from a vessel. The simulation, based on a complex hydrodynamical model of a merchant ship, which compares 3 variants of this manoeuvre, shows that the Scharnov turn is the shortest and the quickest one, but the ship finishes the Anderson turn with the lowest velocity. Also, the time of the Williamson turn is short enough, to successfully finish the operation. The duration of MOB manoeuvres is likened to the results of a medical overview, with not only the duration of MOB, but also the time between falling overboard and the beginning of the manoeuvre playing a crucial role in saving a casualty's life.

Introduction

Man-overboard

Man-overboard (MOB) is one of the most infamous situations that may happen to a seafarer. Depending on numerous variables it can be lethal or may leave the person involved virtually unharmed. It is therefore significant for the ship's personnel to act instantly and execute the exact recovery methods so that the life of the individual in the water is not endangered. Some of the reasons why seafarers go overboard in the sea are as follows (Mukherjee, 2017):

- Slipping on ratlines or on a board;
- Being swept overboard by waves;
- Being pulled by mooring lines;
- Falling from an accommodation or ladder;
- Climbing on to or sitting on the ship's railings;
- Being under the influence of alcohol or drugs;
- Working in low visibility or in rough sea conditions.

In the years 2003–2007 in the USA alone, MOBs were 24% of all boating fatalities (Neale, 2012). Most of them happened on small boats and in good conditions (76% during the daytime and 90% in non-windy time). These statistics encourage one to think about the reason for so many deaths. The answer is probably recklessness, which is further indicate by the facts that a significant proportion of young men were involved in fatal accidents and that 27% of deaths were due to overuse of alcohol. Lack of support also led to most of these accidents, because about 75% of fatal accidents happened on 1 or 2-person vessels. In other research, it was found that 77 – 86.2% – of the people who drowned did not wear a life-jacket (USA Coast Guard, 2012).

This problem ought to be shown also from another perspective. Statistics which describe the passengers of cruise ships are similar. Here, young men also most often went overboard and the reasons for that were alcohol and bravado. Only 21% of cruise-ships passenger survived falling overboard; first, because their disappearance was very noticed only after many hours; second because of lack of manoeuvrability of those ships in comparison to small boats; and lastly because of lack of training on how to behave in cold water (TravelPage, 2018).

In regard to the initial situation, the man-overboard scenario may be classified as one of the following three situations:
- immediate action – the victim is seen directly from the bridge and rescue actions onboard are executed with no delay;
- delayed action – the victim is seen by a witness (e.g., co-worker) standing nearby. The information is then transferred to the bridge with the minimum possible delay;
- reported missing – the victim is found to be missing during a particular event involving checking presence of the personnel; commonly it is a meal-time.

Generally, the course of initial actions undertaken by a crew should more or less follow a set schema, such as the following:
- throwing a life-ring over the side as close as possible to the person in the water;
- informing the master, radio operator or OOW and other members of the crew;
- sounding three prolonged blasts of the vessel's whistle;
- yelling "Person overboard" etc.;
- commencing a particular recovery manoeuvre;
- noting position, wind velocity and direction, the time, in the bridge logbook;
- putting engine-room on standby;
- posting look-outs to keep the person in sight;
- setting off a dye marker or a smoke flare;
- preparing lifeboat for a possible launching;
- distributing portable VHF radios for communication between bridge, weather deck, and lifeboat.

Man overboard manoeuvres

Whenever a person is reported missing, there is a high probability that the victim may be already drowning. Due to that, the man-overboard manoeuvre has to be executed as soon as possible; the time plays a crucial role when it comes to the effectiveness of the action.

There are many factors that determine the efficiency of the MOB manoeuvre, among which the most important are (IMO, 2010):
- manoeuvring characteristics of the vessel;
- sea state and wind direction;
- experience and qualifications of the crew;
- geographical location of the accident;
- visibility level;
- the immediate capability of the engine plant;
- method of collecting MOB;
- the possibility of acquiring assistance from nearby ships.

Assessing the recovery technique used in the event of a person falling overboard is the main objective of this paper. In order to do this, the widely acknowledged recovery techniques are to be briefly explained.

The most commonly taught method is the Williamson turn. It is regarded as a simple manoeuvre. The main aim is to make good to the original track line, yet with opposite course. Although it is considered effective even in reduced visibility, due to the mathematical principles of its execution, it is deemed rather slow and, in the initial part, it does take the ship farther away from the scene of the incident. An example of the Williamson turn is shown in Figure 1; the procedure may be summarised in the following points:
1. Rudder hard over, to the side of the casualty.
2. After deviation from the original course by 60°, rudder hard over to the opposite side.
3. When heading 20° short of the opposite course, rudder to midship position and ship to be turned to opposite course.

Another technique undertaken in MOB situations is the Scharnov turn. Although it bears an obvious

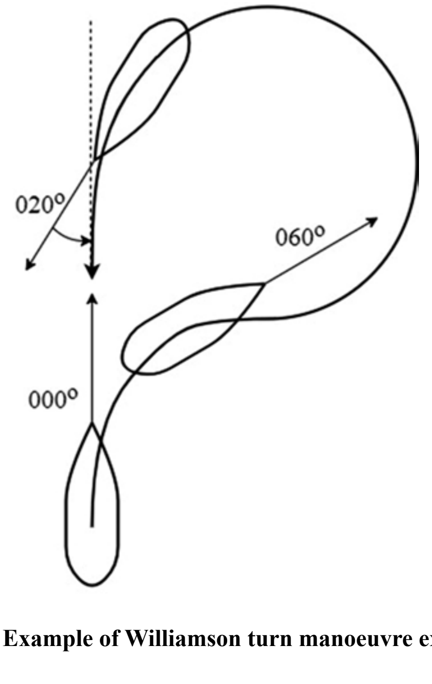

Figure 1. Example of Williamson turn manoeuvre execution

resemblance to the previous manoeuvre, it has different uses; namely, it allows constant visual contact with the survivor. Yet again, it cannot be fully implemented in the case of an immediate action situation, unless the time elapsed between the accident and the commencement of the manoeuvre is known. It does allow the vessel to return to her wake but it ought to be used in a delayed action scenario. The technique is shown in Figure 2; since the manoeuvre is a mirror image of a Williamson turn, the steps do not need to be provided in this paper.

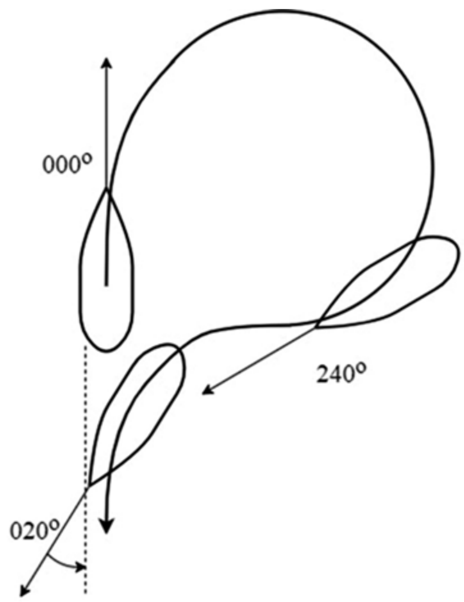

Figure 2. Example of Scharnov turn manoeuvre execution

The last of the three techniques is the Anderson turn, also known as single turn or as 270° manoeuvre. It is undoubtedly the fastest recovery method, good for ships with a compact turning circle. That notwithstanding, the non-straight approach may create difficulties for a single-screw vessel due

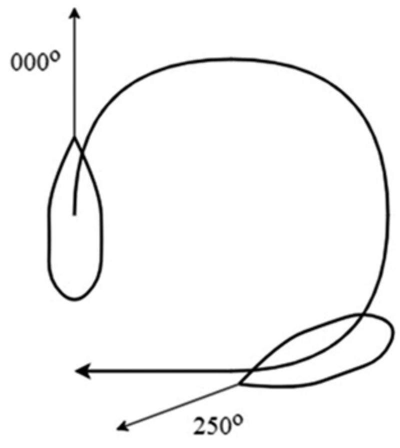

Figure 3. Example of single turn manoeuvre execution

to a common problem with low track stability. An example of this method is shown in Figure 3.

On the whole, the planning of any MOB manoeuvre is more difficult than a conventional one because of the individual turning and stopping characteristics of the ship and the need to eventually bring the ship to a halt. It is to be noted that guiding the ship in the direction of MOB is a major but not sufficient part of the rescue mission (Neri, 2016). Another task for picking up a person in the water might be the use of a fast rescue boat; however, to release such a boat would be possible at low speed only after substantial speed loss. Therefore, it might be useful to look for the manoeuvre with the maximum speed loss (Benedict, Fischer & Gluch, 2011). Finally, it should be mentioned that there are dependencies on the initial ship speed and on the available water depth. It is clear to see that adaptation of the manoeuvre plan has to be performed for each single, varied situation parameter. On the other hand, the simulation software module is able to provide the corresponding data accordingly (Baldauf, 2011).

Theory of hypothermia

Hypothermia is a state of the body in which the temperature measured in the rectum or oesophagus or on the eardrum is below 35°C or 95°F (Szczeklik, 2017). The body temperature falls below the correct range because heat production is smaller than heat loss. It is crucial to distinguish three causes of hypothermia: not enough heat production, too great heat loss and temperature lowering caused by both of these reasons.

Hypothermia is a major threat for people in the water, because this fluid is a much better heat conductor than air. Hence, the heat loss could be even 20–30 times higher than in air. It is obvious that a body cannot deal with such a dynamic process. The increase of heat production (shivering and constriction of skin vessels) is barely capable of slowing this negative process, let alone halting it completely. Another way to fight hypothermia is to take a specific position, with elbows crossed by the chest and bent-up knees (WHO, 2007). Avoiding unnecessary movement is vital. It has been proven that this position may increase the survival time even threefold, provided that one is equipped with a life jacket (WHO, 2007).

When body temperature gets below 32°C (90°F), muscles cease to contract. If the body temperature is lower than the this, it is impossible to stay on the surface without a life-jacket. Around 26°C (79°F) the person loses consciousness. As the temperature gets lower, the heart action gets slower and reflexes get weaker. Body temperature below 24°C (75°F) is likely to be fatal.

Figure 4 shows the time of probable survival in a specific temperature of water. Results shown here are approximate and depend on many factors, e.g. body surface to body volume ratio (thin people lose their heat faster), age, metabolism pace, strength, inherited and acquired abilities to prevent hypothermia (Button et al., 2015).

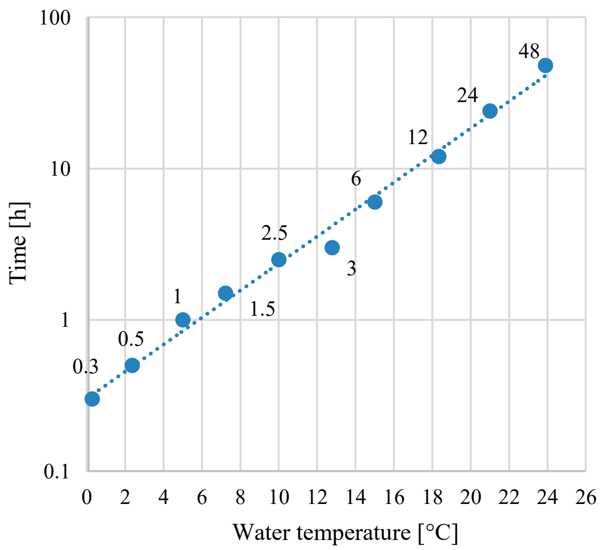

Figure 4. Survival time as function of water temperature (Button et al., 2015)

Cold shock response can kill much faster than hypothermia. This process is associated with a reduction of brain flow. The rapid decrease of surrounding temperature could lead to hyperventilation (which could result in choking) or tachycardia (Stjepanovic, Nikolaidis & Knechtle, 2017). The victim also suffers from dyspnoea. Such reactions could be lethal, especially for people with heart problems. The first seconds in cold water may lead to the drowning of people without life-jackets, even if they are able to swim, because it is hard to coordinate movements. Even rapid MOB does not guarantee the effectiveness of first aid after cold shock response.

Hypothermia is a significant phenomenon, but a person without a life-jacket or with health problems will probably die before the body temperature falls below 24 °C (75 °F). That is why maintaining safety levels onboard and good medical care of the crew could lead to a similar increase in MOB effectiveness to that from MOB training. It is worrying that only 8% of non-swimmers were wearing life-jackets at the time of the fatal accident (Neale, 2012).

Methods

The scenario is based on the following assumptions:

- The manoeuvring data provided in this article are generated using a hydrodynamic model of a ship's behaviour. The state vector of a vessel in this mathematical model is expressed as follows (Kulbiej, 2017):

$$\mathbf{S} = \begin{bmatrix} x & y & \psi & u & v & \omega \end{bmatrix}^T \tag{1}$$

where:
x, y – the position coordinates;
ψ – the heading;
u, v – longitudinal and lateral velocities of the hull;
ω – the radial speed.

- The mathematical model is based on 3 degrees of freedom of the Newtonian dynamic of a rigid body (Kulbiej, 2017). Therefore:

$$\begin{cases} \dot{u} = \dfrac{F_x}{m_1} + \dfrac{m_2}{m_1} rv \\ \dot{v} = \dfrac{F_y}{m_2} - \dfrac{m_1}{m_2} ru \\ \dot{r} = \dfrac{N}{I_{zz}} \end{cases} \tag{2}$$

where:
F_x, F_y, N – sums of forces and momentum;
m_1, m_2 – effective masses of a ship in longitudinal and lateral directions;
I_{zz} – the effective momentum of inertia.
Effective mass and momentum of inertia stand for a corrected value of the body in respect for the added masses of water (Kulbiej, 2017).

- Finally, the sums of forces and momentum can be described as a function:

$$\begin{bmatrix} F_x \\ F_y \\ N \end{bmatrix} = f\left(t, x, y, \psi, v_x, v_y, \omega, \mathbf{G}, \mathbf{C}, \mathbf{E}, \mathbf{S}\right) \tag{3}$$

where:
F_x, F_y – the resultant forces affecting the vessel in X and Y directions;
N – the resultant momentum.
All of these are a compound function of the following variables:
t – time since the commencement of the simulation;
x, y – initial position of the vessel;

ψ – course of the ship;

v_x, v_y – velocities of the vessel alongside the X and Y direction;

ω – ship's radial velocity;

G – vector responsible for ship's hull parameters;

C – vector responsible for ship's control parameters;

E – vector responsible for the environmental situation (weather and hydrological circumstances);

S – vector responsible for surrounding's parameters.

- the meteorological situation included in the paper is assumed as follows:
  - wind velocity is 20 knots, NE;
  - waves of 2 metres amplitude;
  - no wind or wave-induced current.
- the manoeuvre is executed by a Panamax-size bulk carrier (195 m, 50k DWT).
- *XY* coordination system with metres as the main unit is used as a datum.
- Williamson, Scharnov and Anderson turns are used as the recovery techniques. The authors decided to include the Scharnov turn's results, notwithstanding the fact that it is nearly identical to the Williamson turn.

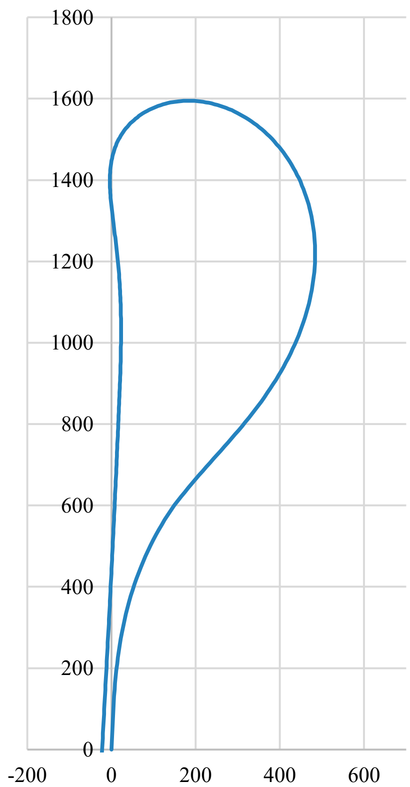

Figure 5. Ship's trajectory during the Williamson turn manoeuvre

Models

The situation described in the previous paragraph has been analysed in respect of three different methods of MOB manoeuvres. The results are shown in Figures 5 to 7.

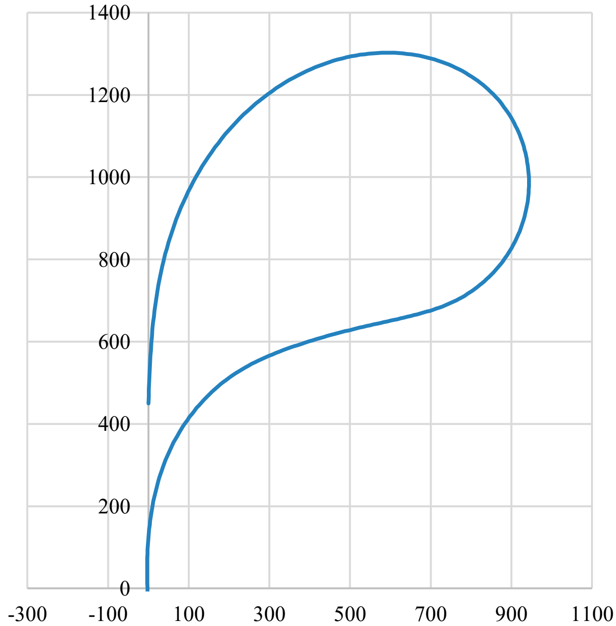

Figure 6. Ship's trajectory during the Scharnov turn manoeuvre

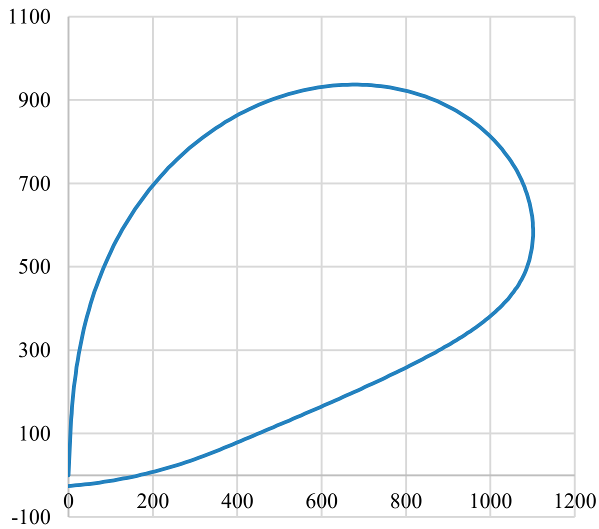

Figure 7. Ship's trajectory during the Anderson turn manoeuvre

Discussion

The main characteristics of the manoeuvres are displayed in Table 1. As it turns out, the manoeuvres do not typically have a similar duration. Specifically, the Williamson turn takes 732 seconds, while the Anderson takes 604 seconds, which makes it approximately 20% shorter in time. Scharnov places roughly in the middle, with 7% longer duration than Anderson, but 10% shorter than the most popular. A similar fact is seen in the distance comparison. As far as final speed is concerned, the difference, in favour of the Williamson, stems from the fact that. on the longer trajectory, the ship had more space to accelerate after the loss of velocity due to the circulation ceasing.

Table 1. Characteristics of turns

Trait	Williamson turn	Scharnov turn	Anderson turn
Duration	732 s	648 s	604 s
Length of trajectory	3584 m	3213 m	3221 m
Final velocity	6.42 m/s	5.57 m/s	6.13 m/s

Regarding the trajectories themselves, it is hard to say that they bear great resemblance to the ones specified in the theory of manoeuvring. It is noteworthy that the hints specified in the literature are of general nature and cannot be applied directly to every ship. The Panamax model used in the simulation tends to be somewhat more manoeuvrable than average. In the case of the Anderson turn, after completing most of the typical circulation, the rudder needed to be put into 0 degrees in order to cease the radial velocity and keep on the course to the initial position.

The Scharnov turn tends to differ, as it commences 450 metres from the initial position P(0,0). It makes the method superior in cases other than immediate action, but less effective in that case.

Transas has undertaken similar calculations for the mathematical model of their simulator (Transas, 2006). The duration of the MOB manoeuvre (Williamson Turn), according to them, is 13 minutes and 43 seconds. It makes the manoeuvre 12% longer in time than was shown in this paper. Yet, the simulation executed for the Transas work did not include the effect of braking and stopping the vessel near the commencing position.

The duration of each manoeuvre is, in most cases, much shorter than the body's cooling time, even after taking into account the need to release before dropping the lifeboat. The low efficiency of persons overboard manoeuvres results from a long period between falling overboard and the beginning of a manoeuvre, as well as from losing the victim from the field of view during the action or not finding the victim.

Conclusions

Regarding the numerical experiment undertaken, the following conclusions were drawn:

- The greatest threat to an overboard person is that of water temperature. In a temperature of 5°C, one may survive 30 minutes on average, which makes the rescue operation a race against time. For this reason, the fact of noticing that a person fell overboard, rather than finding them missing, is of extreme importance; especially in polar regions, it may be the deciding factor for the success of the recovery action.
- Simulations executed for the purposes of this paper aimed to provide a numerical overview of how the recovery manoeuvre should look in actual situations. The simulation was proven credible, albeit it does not bear a close resemblance to the usual theoretical description.
- The results received in the experiment are comparable to those of different sources.
- Due to the numerical differences in length and duration, the Anderson turn seems to be more applicable than Williamson's. That notwithstanding, it is the latter that has gained most notice and is thus deemed most effective.
- In case of a delay before the person overboard is missed, the Scharnov turn should be applied, as it naturally takes the distance offset into account.

Further research undertaken by the authors will focus on including several practical aspects of MOB manoeuvres not covered in this paper, among which are the search pattern, rescue coordination, deployment of mobile rescue units and collecting the survivor.

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