

## Ship's behaviour during hurricane Sandy near the USA coasts. Simulation results

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**Abstract.** The aim of this study is to analyze the impact of the stormy weather during hurricane Sandy on an oil tank using the navigation simulator. Meteorological and waves maps from forecast models are used, together with relevant information from the meteorological warnings. The simulation sessions were performed on the navigation simulator from the Constanta Maritime University and allowed us the selection of specific parameters for the ship and the environment in order to observe the ship's behavior in heavy sea conditions. Simulation results are important due to the unexpected environmental conditions and the ship position: very close to the hurricane centre when the storm began to change its track and to transform into an extra tropical cyclone.

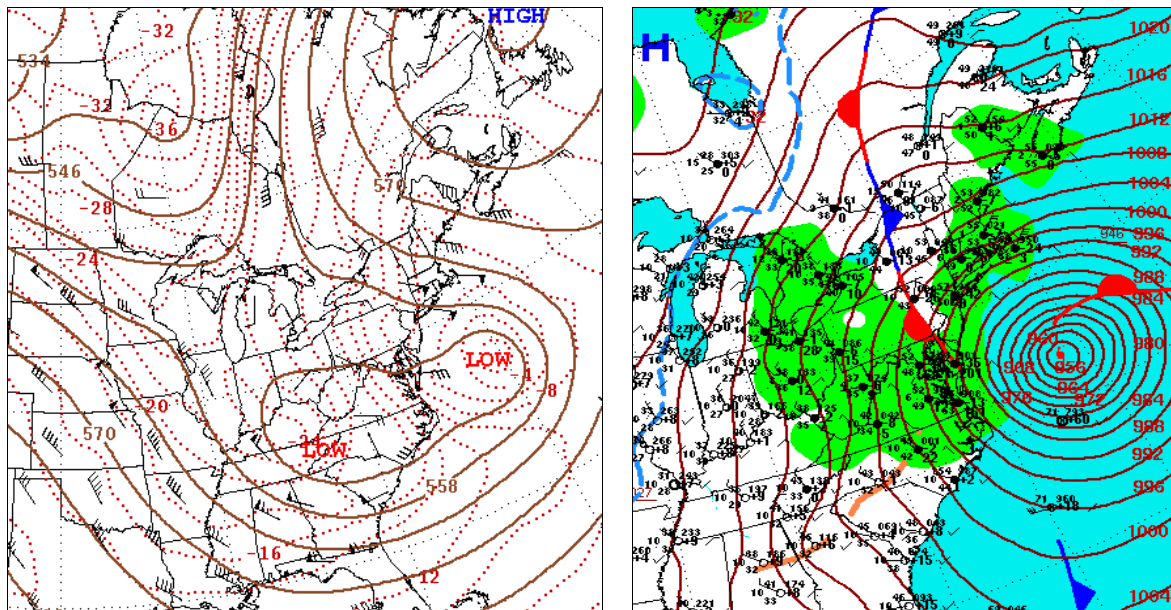
### 1. Introduction

The simulations of the ship route and behaviour were performed on a deck simulator. Specific parameters for the ship and real meteorological data, recorded during the cyclone passage, were used during the simulation. The aim was the reconstruction of a real situation – an oil tank drift on October 29-30 2012 and the analysis of the vessel's movements. The simulation results are important from the safety point of view; they could contribute to a better understanding of ship movements in heavy seas.

Tropical cyclones are no longer a threat to life and maritime activities when they move to higher latitudes. Some could however evolve to fast-moving extra tropical cyclones that produce rainfall, large waves and strong winds. The modeling of this transformation is currently considered as one of the most challenging forecast problems [1]. That is the case of hurricane Sandy, the most notable storm of the 2012 season [2]. It was different from other hurricanes in the area because of the lack of an eye, the track, the large horizontal extension and the transformation into an extra-tropical cyclone. Sandy developed from a category 1 hurricane in Jamaica to a category 3 in eastern Cuba on 23 October 2012, before quickly weakening to a category 1 two days later. It started then to grow in size and moved NE-ward due to a middle - to - upper-level trough (figure1). It regained hurricane strength on October 27. Its structure became unusual, with a large radius of maximum winds, over 100 Nm, the strongest winds located in the western semicircle of the cyclone, the formation of a warm front in the NE quadrant and of another weak stationary boundary to the NW of the center, serving to enhance the convection and strong winds there [3]. Most of the cyclones in the North Atlantic move eastward, which is typical for the extra tropical transition of a hurricane [1]. However Sandy deepened on October 29, SE of New Jersey and began to curve to the west. This track change was due to an upstream trough and its cold air mass. An anomalously high pressure over Atlantic Canada and



Greenland extended from 40° to 60° of latitude. The cyclone movement into the mid-latitudes was to the left of the subtropical ridge over the Atlantic and downstream of the mid-latitude trough located over the USA; the ridge was situated between the eastward propagating trough to the west and a cut-off low to the east of it. The cyclone intensified as cold continental air encircled the warm core vortex; the intensification occurred in response to shallow low-level convergence below 850 hPa (850 hPa charts are not shown in this paper). The cyclone weakened and slowed over the continent, while following a northward movement.



**Figure 1.** NCEP Reanalysis maps (500 hPa geopotential - left, sea level pressure - right).

### 1.1. Cyclone's track and ship's route planning

The meteorological forecast of Sandy's lowest central pressure (an indicator of hurricane's force) in the ECMWF analysis, of 947 hPa, was very similar to 946 hPa estimated by the NHC [5, 3]. Comparisons of several forecast models highlighted that the ECMWF model was one of the first to show the NW-ward turn of Sandy, even while most of the rest of the guidance showed the cyclone staying offshore of the East Coast [3, 6, 7]. The turn to the left of the cyclone was sharper for the higher model resolutions [5]. The cyclone's turn and extratropical transition and intensification represented a high risk for the ships in the New York port area.

The oil tank we considered in this study arrived in the port of New York and started the fuel oil discharging operations on October 27 2012. Its main characteristics were: a double hull oil tanker classified as: 1A1 (E), oil carrier, a deadweight of 158000 MT, LOA 274,4 M, LBP 264 M.

The same day at 21H00 UTC a hurricane warning was sent by the Meteorological Office in Washington to all the ships in the area: "hurricane center located near 30.2°N and 75.2°W [...]. Present movements toward the NE or 25 degrees at 11 kts. Estimated minimum central pressure 961 mb, maximum sustained winds 65 kts with gusts to 80 kts" [8]. On October 28, 10H22 UTC, Sandy was: "north of area near 31.9°N/ 73.3°W with 960 mb, maximum sustained winds 65 kt, gusts 80 kt [...] and 270 Nm NW quadrants with seas to 36 FT (significant waves)" [8]. Because of the high risk due to the approaching cyclone, the Captain of the Port of New York and New Jersey [...] "in addition the COTP hurricane severe weather plan" required on October 28: "commercial deep draft vessels greater than 500 gross tons are not authorized to remain in port alongside a pier after 6 p.m. today; all the vessels must be out of Bay Ridge, Stapleton and Gravesend Bay Anchorage Grounds by 6 p.m. today" [9].

That is why the oil tank left the port in the afternoon and was, on October 28/29 under way to north along the USA coasts.

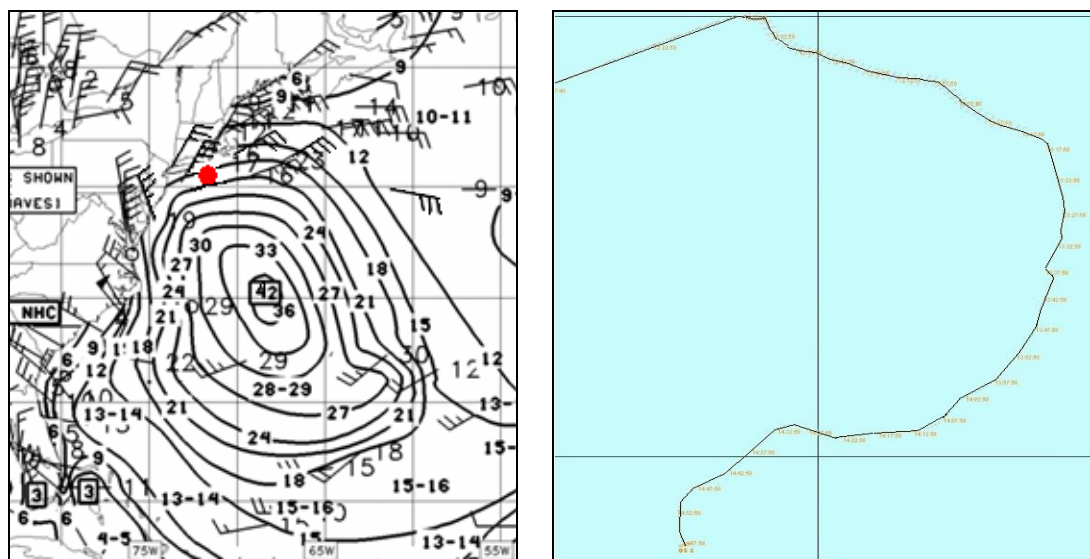
### 1.2. Simulations of the ship's route and behaviour

The deck simulator from Constanta Maritime University allowed us the selection of a specific area and of a type of vessel with identical characteristics to those mentioned above. For a more accurate simulation of different wind forces and sea states, we made several successive tests for different wind speeds and directions and corresponding waves' heights and directions. The input data (wind conditions and sea states) are real meteorological records, done all the 6 or 12 hours and they were extracted manually from the meteorological telegrams [10] and from the weather bulletins and warnings received on board ship.

The simulator's functionalities are however still limited, especially when it comes to the dynamic of the air masses [11]. The present situation was complicated by the fact that the wind changed its direction frequently near the centre of the cyclone.

As a result of the simulation sessions we obtain a progress curve of the ship for a period of several hours which is very similar to the real ship's route from the ECDIS maps (recorded on ship board but not shown in this paper). The progress curve in figure 2, starts on October 29 when the ship tried to move away from the coast. The ship went adrift starting with 29.10.2012, 13H00, because of the very rough sea. The storm waves were pushing the ship to the shore so the oil tank had to change its course starting with October 29, 1H p.m. and to head to the east. The ship began therefore to move away from the initial course in a ESE direction but very quickly afterwards it was gradually pushed to SW and then W by the large waves (figure 2).

Three days later, after hurricane Sandy landfall, the ship headed back to the port of New York in order to complete the unloading operations. figure 2 (left) shows the approximate position of the ship on October 29, under its way to a place of refuge.



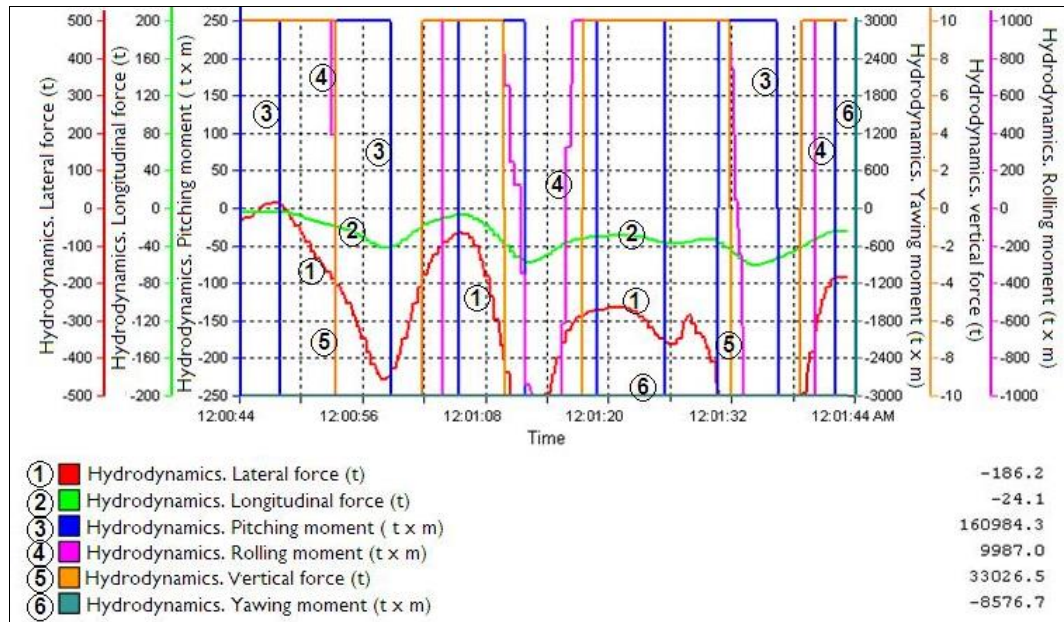
**Figure 2.** Wind speed, significant waves and ship position on 29.10.2012, 13H00, noaa.gov.  
– left; ship's course on the simulator – right.

Variations of hydrodynamics and ship parameters' for periods of 1 and 5 minutes of simulation are shown in figures 3-6. The values on the diagram in figure 4 were recorded at the end of the simulation. Diagrams in figures 3 and 4 show that:

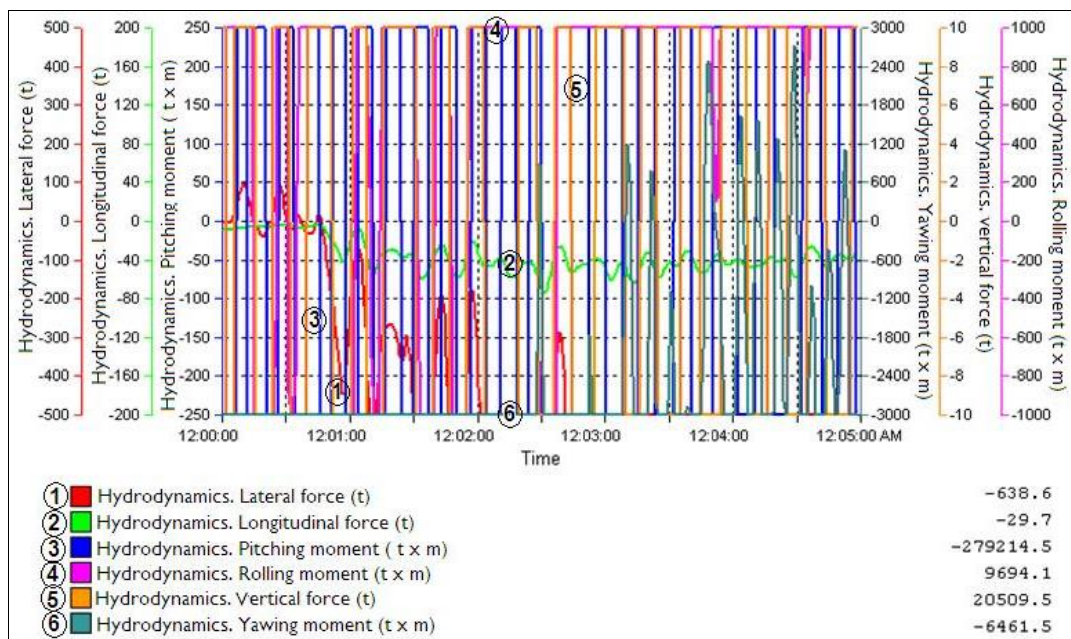
-the pitching and rolling moments (lines 3 and 4), record high values and rapid changes within the negative and positive limits. The high values are normal, considering the heavy pitching and rolling



(roll in figs. 5 and 6), [12]. Ship oscillatory movements around the longitudinal and transversal axis (that define the roll and pitch) are violent; the ship has a continuously motion to port and starboard sides, as well as raising and lowering movements of bow and stern;



**Figure 3.** Evolution of hydrodynamic selected parameters for 1 minute of simulation.



**Figure 4.** Evolution of hydrodynamic selected parameters for 5 minutes of simulation.

Figures 5 and 6 show that:

-the roll angle (line 1) has very high values that largely exceed the limits set for the simulation sessions; the ship has fast oscillatory movements to the port and starboard sides, along its fore-and-aft axis; during this heavy roll, values change rapidly from port to starboard and vice versa. At 12.00.16 the ship have a list to the port side and the next 6 seconds the value exceeds the limit set for the

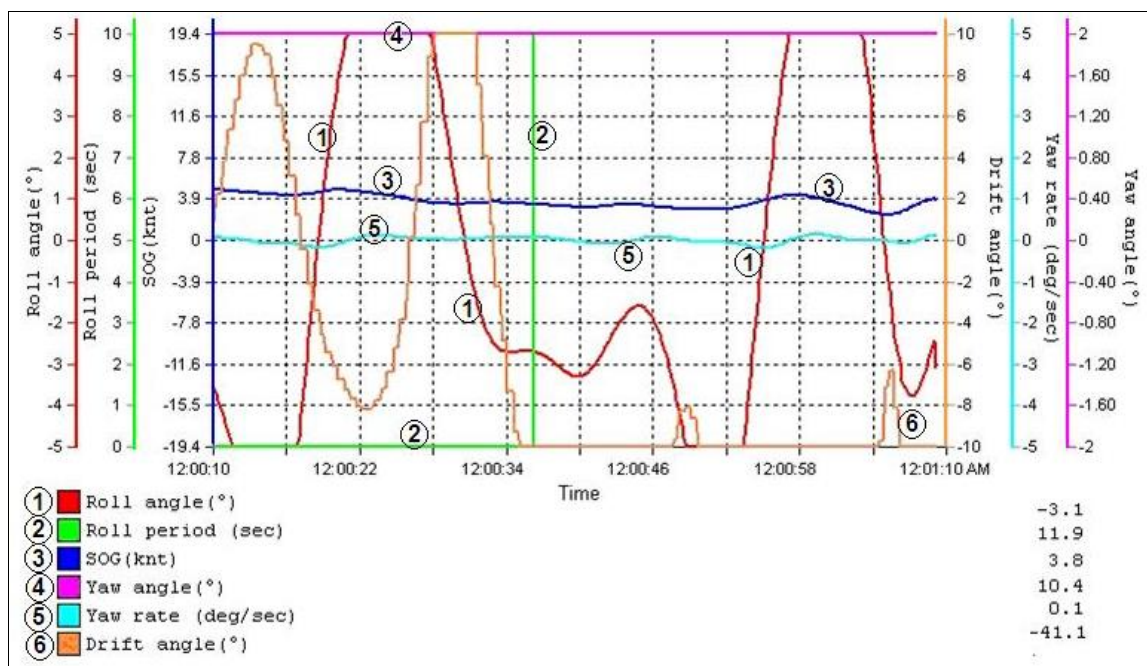
starboard. The diagrams also show that for short periods of time the ship remains 3 degrees list to port side, then the heeling angle becomes greater on the same side, followed by an immediate inclination to the starboard side. This is a violent roll; the vessel loses its equilibrium position because of strong external forces such as wind force and wave impact force.

-the speed over the ground (line 3) has an initial value of 4 knots, with slight variations. During the 90 minutes simulation session, ship speed over the ground decreased, last values being equal to 1 knot or to zero, even if the main engine running is on “slow ahead” and “half ahead”.

-the yaw angle (line 4) is defined as the angle formed by the fore-and-aft line with the ship’s heading line. The movement occurs around a vertical axis passing through the vessel’s centre of gravity and is different from the movement of lateral deviation that occur around a vertical axis passing through the vessel’s centre of gyration.

The variation of the angle of deviation of the extremities is within the maximum limits, to port and starboard sides; this indicates that the extremities of the vessel are in constant motion due to frequent changes of wind direction. As a consequence of the heavy roll, the drafts fore and aft change (any inclination to starboard increases the draft this side and decreases the draft in the opposite side i.e. the port side). Therefore, the increasing draft determines an increase of the hydrostatic thrust forces at the starboard side, larger than the hydrostatic forces on the port side; an additional hydrostatic thrust force appears, that will push the bow to the starboard side and the stern to the port side. Ship’s behaviour will be the same if the ship is inclined to the port side: due to the additional hydrostatic thrust force, the bow is pushed to the starboard side and the stern to the port side.

Bow and stern are continuously drift away and the ship keeps the course only for very short periods: 2 minutes at the starboard side, between 12.01.47 and 12.03.47; then the bow turns to the starboard side where it stays another 2 minutes (from 12.03.47 to 12.05.47), figure 6.

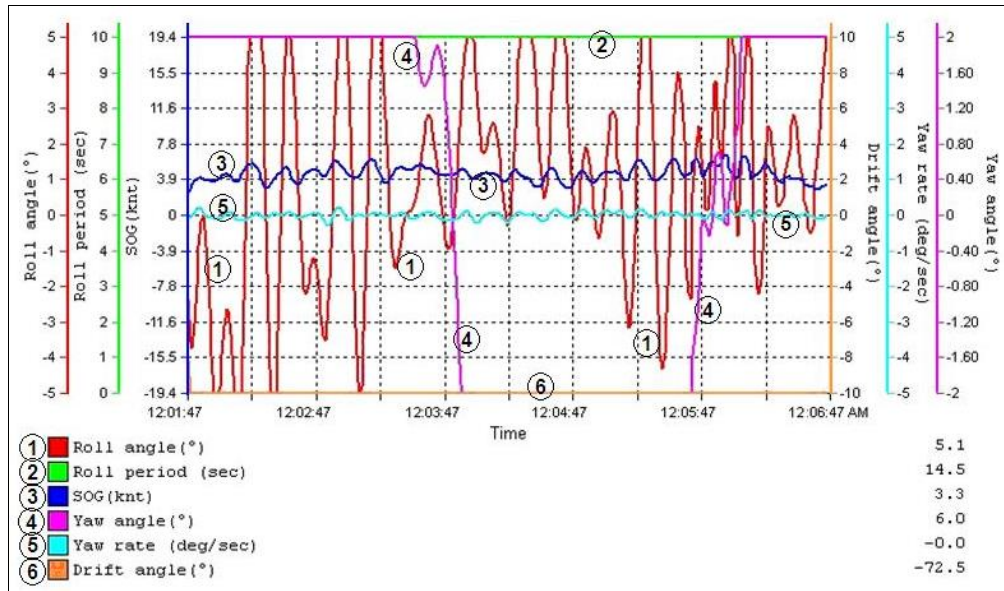


**Figure 5.** Evolution of ship’s selected parameters for 1 minute of simulation.

## 2. Conclusions

Simulations of a ship’s progress curve and ship’s behaviour in heavy seas were conducted on a TRANSAS NaviTrainer 5000. The purpose is a better understanding of ship movements in heavy seas. The simulator allowed us the use of real meteorological input data, the selection of a certain navigation area and of a certain type of ship, and thus restoring a real situation.

The selected ship's and hydrodynamic parameters are the best indicators for ship behaviour in extreme weather conditions. The 1 and 5 minutes periods were chosen because they provide a more detailed representation and a clearer reading of the results. A longer period for 6 parameters that vary continuously would make the results interpretation impossible. The results show dangerous pitching and rolling moments, this aspect being very important from the safety point of view.



**Figure 6.** Evolution of ship's selected parameters for 5 minutes.

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