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Influence of speed reduction on navigational safety of container ships

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Abstract

Paper presents results of a real-time simulation experiment which was carried out to study an influence of speed reduction on the navigational safety of container ships. In order to determine changes in the vessels manoeuvrability set of simulated sea trials was carried out. The tests included the measuring of the movement parameters of ships proceeding with different initial speed in different external conditions.

Introduction

Speed reduction or slow steaming is becoming increasingly popular among container ships operators on Baltic Sea particularly in light of the upcoming emission restrictions [1]. This paper presents results of a real-time simulation experiment which was carried out with use of the computer based Transas Navi-Trainer Professional 5000 (NTPRO 5000) Simulator (Fig. 1).

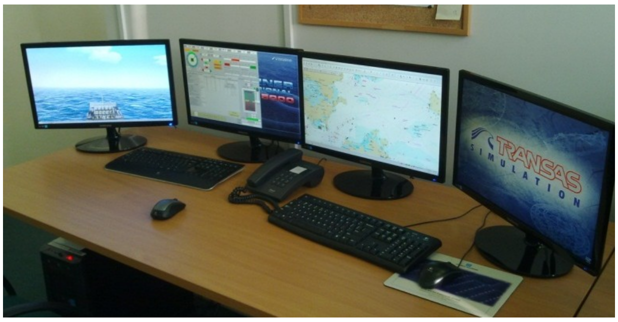


Fig. 1. Work station with NTPRO 5000 simulator

The main goal of the experiment was to study an influence of speed reduction on the manoeuvrability of container ships. In order to achieve the goal set of simulated sea trials was carried out. The tests included the measuring of the movement parameters of ships proceeding with different initial speed in different external conditions.

Assumption of the simulation experiment

Ships models

Simulations were carried out for two sizes of container vessels (Fig. 2), both in fully-loaded condition. The sizes of vessels were chosen with consideration of the characteristic size of the ships navigating in the Baltic Sea area. Particular parameters of the ships models are presented in table 1.

Fig. 2. Simulated container vessels

Both ships models are equipped with standard navigational equipment such as autopilot, GPS / dGPS receiver, echo-sounder, radar with ARPA, ECDIS, log, AIS, etc. NTPRO 5000 enables full interaction between objects (ships models) and environment taking into account all 6 degrees of freedom. It also allows for recording values of dozens of parameters influencing the ship motion [2].

Table 1. Principal parameters of the simulated container vessels

Parameters	Vessel 1	Vessel 2
Capacity [TEU]	1610	4275
Displacement [t]	24080	73910
Length [m]	169	261.4
Breadth [m]	27.2	32.3
Bow draft	8.5	12.6
Stern draft	9.5	12.6

Research area and the external conditions

Research area was chosen as a location with high traffic density [3] and typical external conditions for southern part of Baltic Sea. The initial ship parameters were set as follows:

– position: latitude 51°N, longitude 14°E;
– heading: 000°;
– initial speed: different for different trials.

Depths in chosen area are about 50 m, so it can be assumed that their influence on ship motion is negligible. Simulations were carried out for three wind forces (0, 10 and 20 m/s) and for three relative directions (000°, 090°, and 180°). Heights and directions of waves were determined in accordance with wind force and direction [4].

Executed sea trials

For comprehensive assessment of speed reduction influence on manoeuvrability and navigational safety simulations of following sea trials were carried out:

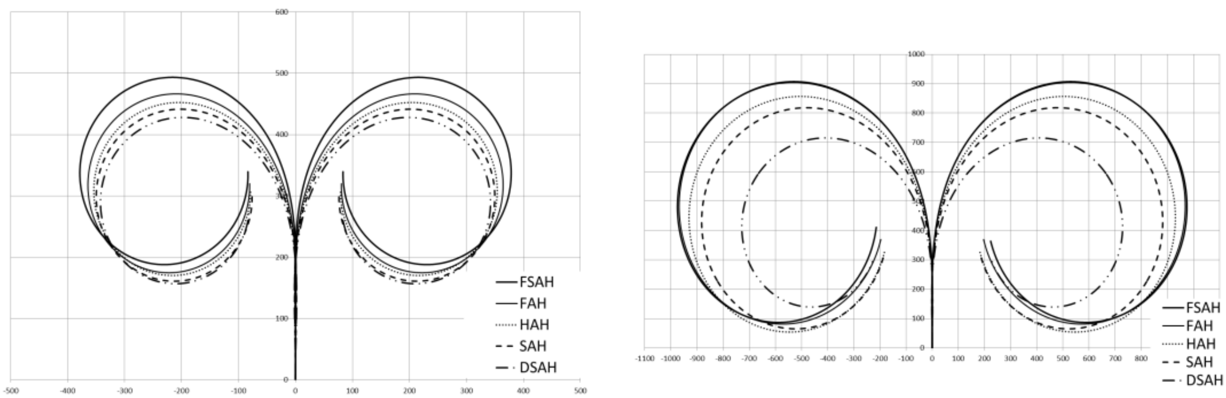
– turning circle;
– zigzag manoeuvre;
– anti-collision manoeuvre;
– behaviour on straight section in different external conditions.

Turning circle

Turning circle tests were performed for both, port and starboard side according to the recommended procedures at speeds from FSAH to DSAH with a maximum rudder angle. It is necessary to do a turning circle of at least 540 degrees to determine the main parameters of this trial.

The essential information to be obtained from this manoeuvre consists of [5]:

– tactical diameter;
– turning radius;
– advance;
– transfer;
– loss of speed on steady turn;
– ROT (Rate Of Turn) on steady turn;
– time of one circulation on steady turn;
– roll angle.



ship 1 ship 2

Fig. 3. Turning circles of 1610TEU (ship 1) and 4275TEU (ship 2) container vessel

Table 2. Parameters of turning circles in meters

	Tactical diameter [m]		Turning radius [m]		Advance [m]		Transfer [m]		ROT on steady turn [deg/min]		Time of circ. on steady turn [min]	
	ship 1	ship 2	ship 1	ship 2	ship 1	ship 2	ship 1	ship 2	ship 1	ship 2	ship 1	ship 2
FSAH	370	961	295	764	482	893	154	424	79	44	4.5	8.2
FAH	356	955	284	784	456	895	152	464	66	30	5.4	12
HAH	346	917	275	762	442	844	146	431	47	23	7.6	15.6
SAH	342	868	273	711	431	805	144	398	35	18	10.3	20
DSAH	335	712	262	518	418	701	142	307	18	13	20.0	27.7

Table 3. Parameters of turning circles in ships length

	Tactical diameter [L]		Turning radius [L]		Advance [L]		Transfer [L]	
	ship 1	ship 2	ship 1	ship 2	ship 1	ship 2	ship 1	ship 2
FSAH	2.2	3.7	1.7	2.9	2.9	3.4	0.9	1.6
FAH	2.1	3.7	1.7	3.0	2.7	3.4	0.9	1.8
HAH	2.0	3.5	1.6	2.9	2.6	3.2	0.9	1.6
SAH	2.0	3.3	1.6	2.7	2.6	3.1	0.9	1.5
DSAH	2.0	2.7	1.5	2.0	2.5	2.7	0.8	1.2

The weather conditions influence was omitted (wind force 0 m/s, no waves). Particular results are presented in tables 2 and 3. The smaller ship is marked as ship 1 and the bigger as ship 2. In table 2 distances are given in meters and in table 3 distances are given in ships length. Figure 3 shows dimensions of turning circles for both ships and for different initial speed. Variations of roll angles for both ships were similar, with maximum value less than 10°.

Zigzag manoeuvre

Zigzag manoeuvres were carried out for both container vessels according to the recommended procedures [5]. The weather conditions influence was omitted (wind force 0 m/s, no waves).

Following results of zigzag tests were gathered:

- Initial turning time (s) – the time from the instant, the rudder is put at the outset of the manoeuvre (first execute) until the heading is 10° off the initial course. At this instant the rudder is reversed to the opposite side (second execute).
- Overshoot angle (°) – the angle through which the ship continues to turn in the original direction after the application of counter rudder.
- Time to check yaw (s) – the time between the rudder execute and the time of the maximum heading change in the original direction.
- Reach (s) – the time between the first execute and the instant when the ship's heading is zero after the second execute.
- Time of a complete cycle (s) – the time between the first execute and the instant when the ship's heading is zero after the third execute.
- ROT (Rates Of Turn).
- Roll angle.

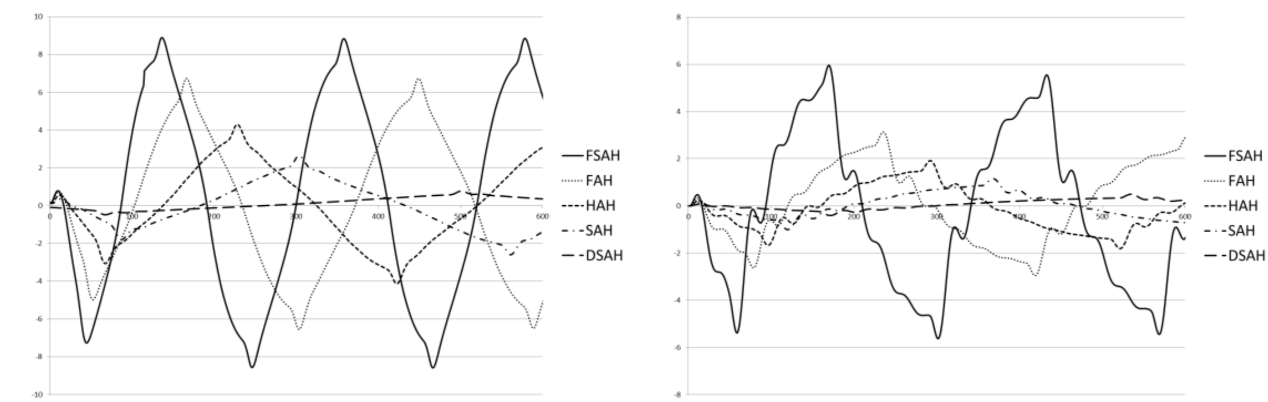
Particular results are presented in table 4. Results for 1610TEU container vessel are marked as ship 1 and the results for 4275TEU container vessel are marked as ship 2. Rates of turn and roll angles are presented in figures 4 and 5.

Anti-collision manoeuvre

Simulations of anti-collision manoeuvres were performed to assess the speed reduction influence

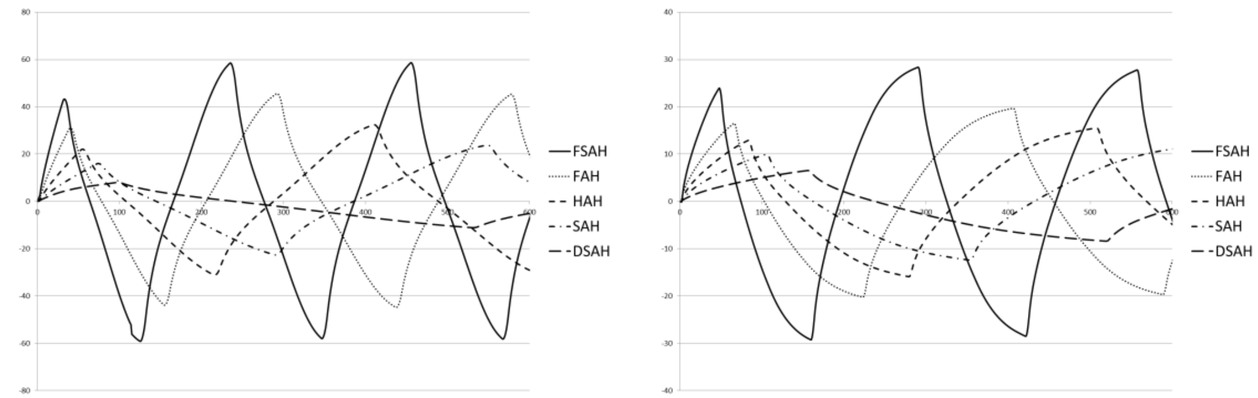
Table 4. Parameters of zigzag manoeuvres

	Initial turning time [s]		Overshoot angle [°]		Time to check yaw [s]		Reach [s]		Time of a complete cycle [s]	
	ship 1	ship 2	ship 1	ship 2	ship 1	ship 2	ship 1	ship 2	ship 1	ship 2
FSAH	32	48	18	8	39	162	115	135	223	266
FAH	39	66	17	8	43	226	140	189	278	372
HAH	53	84	17	7	73	284	194	236	390	464
SAH	73	106	16	7	93	363	261	299	521	591



ship 1 ship 2

Fig. 4. Roll angles on zigzag manoeuvres of 1610TEU container vessel (ship 1) and 4275TEU container vessel (ship 2)



ship 1 ship 2

Fig. 5. Rates Of Turn on zigzag manoeuvres of 1610TEU container vessel (ship 1) and 4275TEU container vessel (ship 2)

Table 5. Parameters of anti-collision manoeuvres

	Time to change heading 30° [s]		Distance traveled to change heading 30° [m]		Distance traveled to change heading 30° [L]	
	ship 1	ship 2	ship 1	ship 2	ship 1	ship 2
FSAH	43	74	432	852	2.6	3.3
FAH	56	105	426	852	2.5	3.3
HAH	78	133	419	803	2.5	3.1
SAH	106	170	414	764	2.5	2.9
DSAH	208	253	405	654	2.4	2.5

on the navigational safety. Simulations were conducted for initial speeds form FSAH to DSAH and rudder angle 15° to starboard side. Following parameters were determined to establish when and in what distance the anti-collision manoeuvre should be started:

– time to 30° heading change;
– distance (advance) covered to 30° heading change.

The weather conditions influence was omitted (wind force 0 m/s, no waves). Particular results are presented in table 5. Results for 1610TEU container vessel are marked as “ship 1” and the results for 4275TEU container vessel are marked as “ship 2”.

Behaviour on straight section

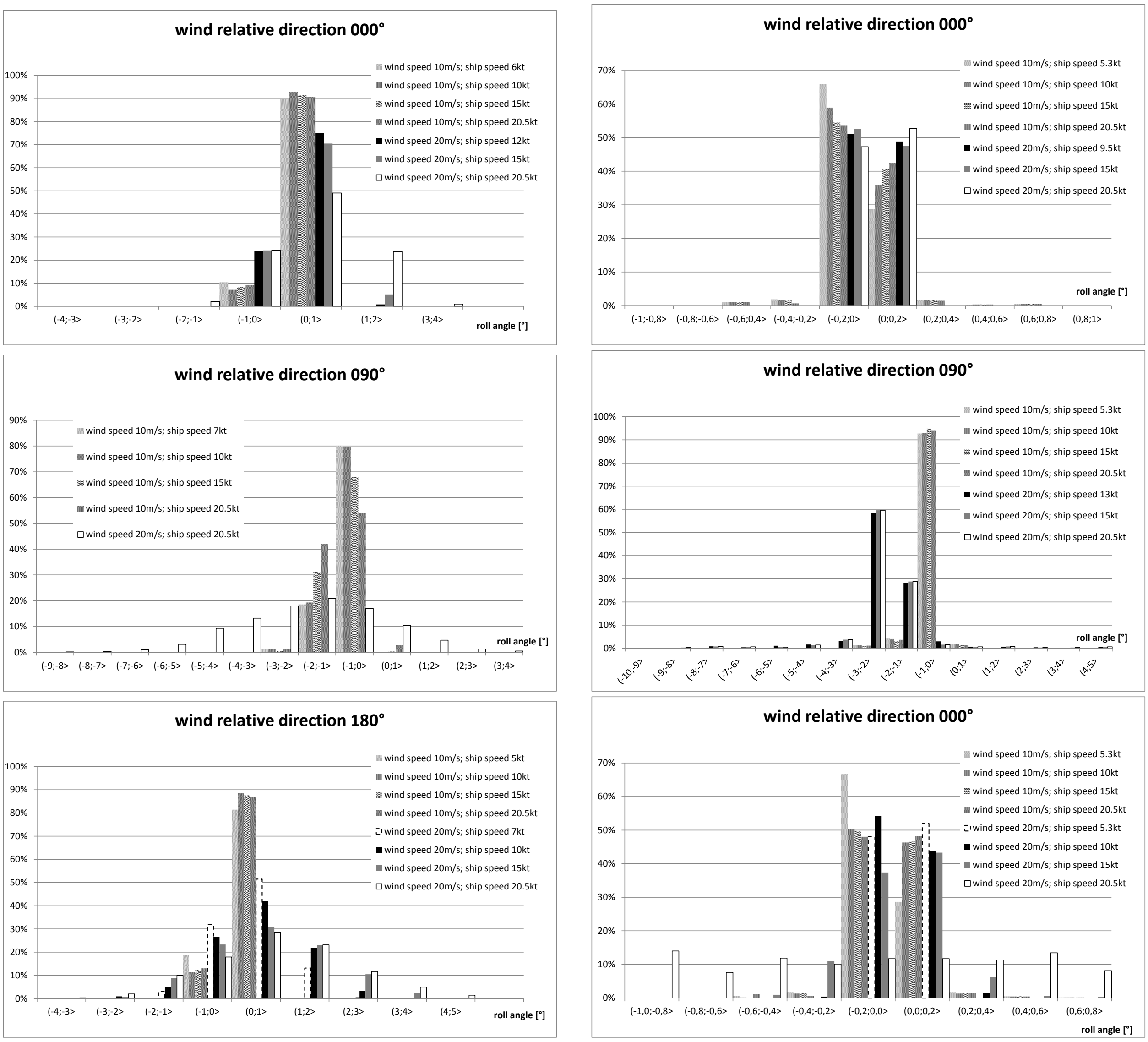
Simulation of ship behaviour on straight section was carried out to estimate speed reduction influence on the ship movement parameters in different external conditions. Following parameters were recorded:

– course-keeping ability;
– rolling;
– pitching;
– rudder angle.

Simulations of ship behaviour on straight section were carried out for both vessels and for different external conditions (wind force: 0, 10 and 20 m/s from relative directions 000°, 090° and 180°, waves height and directions were determined in accordance to wind force and direction). Minimum speeds necessary to keep the course are presented in table 6. Distributions of roll and rudder angles are presented in figures 6 and 7.

Table 6. Minimum speeds to keep the course in different external conditions

Wind speed [m/s]	Wind relative direction [deg]	Minimum speed to keep the course [kts]	
		ship 1	ship 2
0	–	< 5	5.3 (DSAH)
10	0	6	5.3 (DSAH)
	90	7	5.3 (DSAH)
	180	< 5	5.3 (DSAH)
20	0	12	9.5
	90	> 20	13
	180	7	5.3 (DSAH)



ship 1 ship 2

Fig. 6. Distribution of roll angles on straight sections in different external conditions for 1610TEU (ship 1) and 4275TEU (ship 2) container vessel

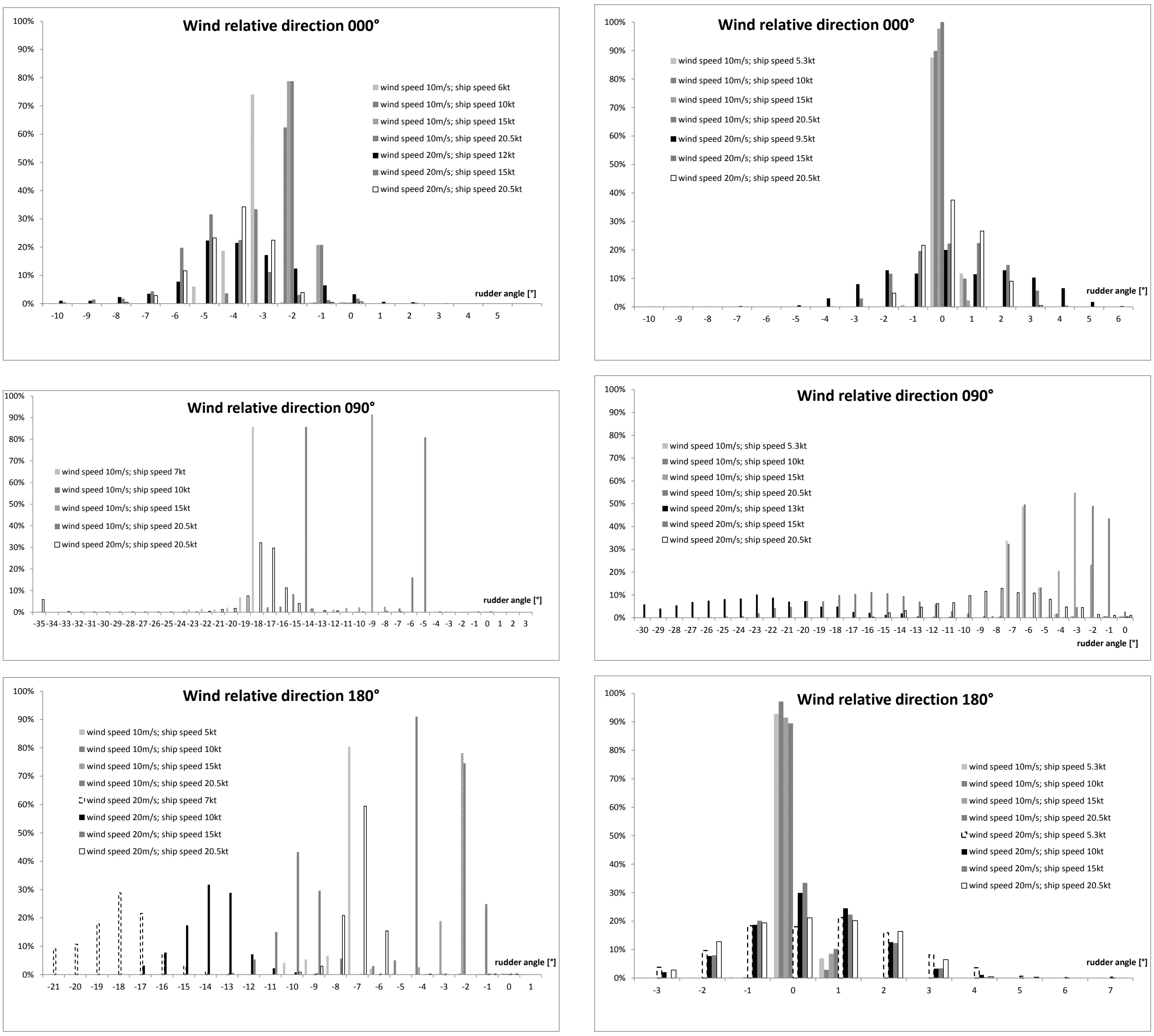
Conclusions

The main issue related to the speed reduction is the ability to maintain on the course in the bad external conditions. It was noticed that during adverse weather conditions vessels had not been able to keep the desired course while proceeding with reduced speed.

Reduction of speed does not have significant influence on spatial distribution of manoeuvres but it has strong effect on the ROT values, durations of manoeuvres and the roll angles. Due to this it should be taken into consideration that all manoeuvres should start earlier.

Particular conclusions:

– Speed reduction does not have significant influence on the dimensions of turning circles. Distinct change was noticed only for bigger ship for the minimal speed (DSAH).
– ROT, time of one circulation on steady turn and the roll angles strongly depend on the initial speed of vessel. The higher the initial speed is the higher is the ROT and the bigger are the roll angles. If the ROT is higher the duration of one circulation is shorter.
– All time-parameters measured during zigzag manoeuvre are dependent on initial speed. The higher the speed is the less values of parameters were determined.
– Slight changes in overshoot angles were noticed for different initial speeds. For smaller vessel from ca. 18° (FSAH) to ca. 16° (DSAH) and for bigger one from ca. 8° (FSAH) to ca. 6° (DSAH).
– Roll angle values on the zigzag manoeuvres are higher for the higher initial speed, values vary



ship 1 ship 2

Fig. 7. Distribution of rudder angles on straight sections in different external conditions for 1610TEU (ship 1) and 4275TEU (ship 2) container vessel

between ca. 1° (DSAH) and ca. 9° (FSAH) for smaller vessel and between ca. 0.5° (DSAH) and ca. 6° (FSAH) for bigger vessel.

– Distances travelled during anti-collision manoeuvres are similar for all initial speeds, but the times of manoeuvres differ significantly. Maximum increase of time delay for anti-collision manoeuvre for DSAH in compare to FSAH is around 3 minutes which cause necessity to plan the manoeuvre earlier but does not influence significantly safety of navigation.
– Restrictions in speed reducing resulting from minimal speed necessary to maintain the desired course were observed. For smaller vessel and for wind speed 20 m/s from 090° relative direction minimum speed was higher than 20 knots.
– For simulations where the dependence between initial speed and the rudder angle was noticed it was observed that the higher the initial speed is the less values of rudder angles are necessary to maintain the course.
– Observed rudder angles higher than 15° will significantly influence effectiveness of steering system and increase rudder dragging forces.

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