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Improvement of Manoeuvring Properties of Inland Navigation Units by Using the Magnus Effect

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ABSTRACT: Due to the ongoing climate change, the European Commission is implementing the promotion of inland waterway transport. By creating favourable conditions for the further development of the sector, the Commission hopes to encourage more companies to use this mode of transport. The policy to promote inland waterway transport in Europe is encapsulated in the NAIADES Action Programme. Carriage of goods by inland waterways is climate-friendly and energy-efficient and can significantly contribute to sustainable mobility in Europe. The European Commission believes that transport by inland waterways must be better used in order to relieve heavily congested transport corridors.

In inland navigation, we are dealing with water areas of relatively small depths, therefore the units - pushed convoys carrying out the transport task in these areas have a shallow draft. The small draft of the units, as well as the shape of the hull, which is flat-bottomed, makes such a unit very sensitive to hydro-meteorological conditions. At the same time, the shape of the underwater part of the hull greatly influences the maneuverability of the vessel, especially when turning, taking up a large maneuvering space.

The number of inland waterway accidents and claims for damages has been increasing year by year since 2014. The value of claims for damages is also growing. According to Paul Goris, President of the IWT Platform, “The inland shipping sector is on the verge of a major transformation in terms of sustainability and digitalisation. This requires further development of standards and certain security requirements”

1 INTRODUCTION

Due to the ongoing climate change, the European Commission is implementing the promotion of inland waterway transport. By creating favourable conditions for the further development of the sector, the Commission hopes to encourage more companies to use this mode of transport. The policy to promote inland waterway transport in Europe is encapsulated in the NAIADES Action Programme. Carriage of goods by inland waterways is climate-friendly and energy-efficient and can significantly contribute to sustainable mobility in Europe. The European Commission believes that transport by inland waterways must be better used in order to relieve heavily congested transport corridors .

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2 MARINE CASUALTIES AND INCIDENTS - INLAND TRANSPORT

Marine casualties and incidents, data based on Annual overview of marine casualties and incidents 15.12. 2021 EMSA (European Maritime Safety Agency) has introduced the following definitions:

As defined by EMSA:

- Inland waters, which includes any area of water defined by EU Member States and not categorized as 'sea'- e.g. canals, tidal and non-tidal rivers, lakes, and some estuarial waters (an arm of sea that extends inland to meet the mouth of a river)
- Inland waterway vessel is a vessel intended solely or mainly for navigation on inland waterways.

In conclusion, in the year 2020 signified the reduction or stability of some indicators such as the number of ships involved, the number of fatalities or injured persons, etc Impacts of COVID pandemic should, however, be considered, due, for example, to restrictions on recreational crafts during lockdown periods or reduced traffic by inland waterway vessels

Inland waters – Marine casualties and incidents

Table 1. Inland waters - Distribution of marine casualties and incidents [4]

Year	2014	2015	2016	2017	2018	2019	2020	Total
No. of accidents	69	58	66	46	113	106	59	517

Table 2. Inland waters - Marine casualties and incidents per ship type for 2014-2020 [4]

Chemical tanker	32
Liquid gas tanker	7
Oil tanker	37
Other/Unspecifed liquid cargo	7
Bulk carrier	104
Container ship	60
General cargo	179
Ro-Ro cargo	13
Other Solid Cargo	15
Other/Unspecifed cargo	3
Total	457

Table 3. Inland waters - Distribution of marine casualties and incidents per cargo ship type for 2014-2020 [4]

Cargo ship	457
Fishing vessel	11
Passenger ship	52
Service ship	50
Other ship	33
Grand Total	603

According to marine casualties and incidents data based on an analysis of accidents on inland waterways CESNI Strasbourg · October 2020 and the research [5], on inland waterway failures, were based on transport on the Danube River on the section 1870 - 2200 km of Austria. In the period: March 21, 2002 – October 4, 2017, 584 accidents involving 754 inland waterways were registered.

The following accident types have been recorded:

- Allision: a moving ship collides with a fixed object (bridge, riverbank, part of the fairway, infrastructure, another ship that was not moving at the time of the accident).
- Collision: Two moving ships collide.
- Grounding: the ship has run aground, contacting the bottom of the fairway.

Breakdown of accident types;

- Allision 46%
- Collision 25%
- Grounding 27%

Cause of the above-mentioned accidents:

- Human failures (HF):
  - fatigue (a brief sleep or a loss of concentration)
  - failure to follow established procedures
  - abuse of alcohol
  - misunderstanding or lack of communication
  - misjudgment of navigational conditions
  - insufficient situation awareness.
- Technical fault (TF), e.g. a machinery or navigational equipment failure.
- Weather conditions (WEC):
  - gusty wind, fog, precipitation, ice, etc.
  - water level fluctuations (low water periods, high water periods).

3 INFLUENCE OF THE WIND ON THE MANOEUVRABILITY OF THE UNIT. IMPROVED MANOEUVRABILITY

Taking into account the wind, its direction and speed, the conditions under which the ship can be maintained in strong wind are presented below [3].

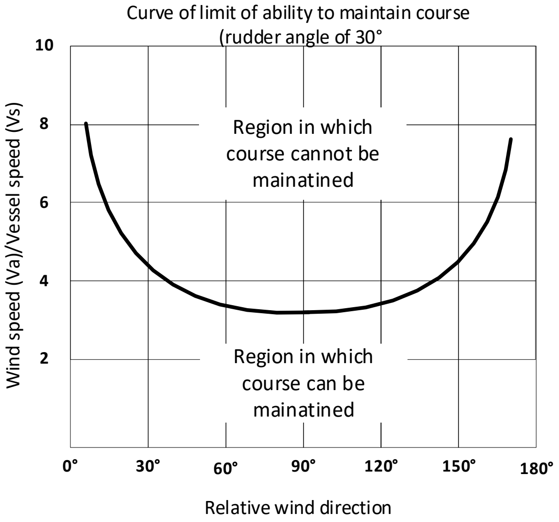


Figure 1. The area in which the manoeuvring vessel will not be able to keep the course due to the wind speed and direction is marked on the drawing.

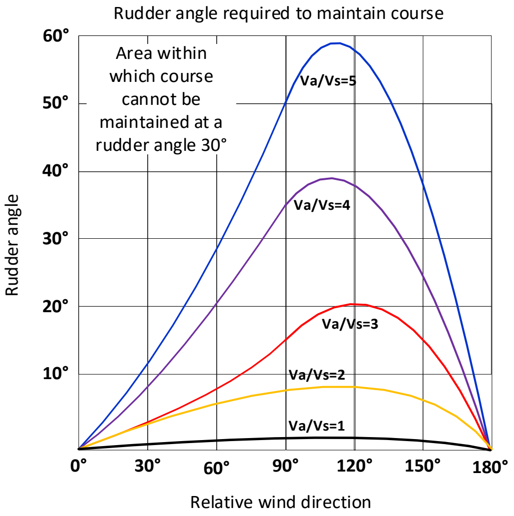


Figure 2. The chart shows the rudder angle on the vertical axis and the areas where the course cannot be maintained for the ratio of wind speed to ship speed (V_a/V_s)

The improvement of manoeuvring properties can be achieved by e.g. increasing the rudder area, many structures have been developed to improve manoeuvring properties, increasing the safety of navigation.

Increasing the dimensions of the rudder reduces the time of the manoeuvre. For example, the ratio of the rudder area to the area of the submerged hull it varies from 0.017 for a cargo ship to 0.025 for destroyers.

$$Rudder\ Area\ Ratio = \frac{Rudder\ Area}{LppT}$$

Work is underway to improve the level of safety and manoeuvrability of the unit and pushed convoys through the use of new steering devices and the use of special rudder constructions.

An example of a solution was the open rudder called "Rudder Doerffer", which was first installed in the late 1980s on the Polish tugboat "Achilles". Despite its advantages, it was not accepted as an innovative solution of the steering device improving manoeuvrability.

New rudder blade solutions are introduced, e.g.:

- Schilling rudder : The fish-shaped rudder improves both course keeping and maneuverability
- Flap rudder : These rudders consist of a movable rudder with a flap on the trailing edge,
- Articulated coupling [7]: Articulated coupling between pusher and push lighter, incorporating a hydraulically operated flexible coupling.

Figure 3. Schilling rudder, Flap rudder, Articulated coupling

4 SELECTED REQUIREMENTS OF CLASSIFICATION SOCIETIES REGARDING THE MANEUVERABILITY OF THE UNIT

Manoeuvring properties are determined by two basic parameters: steerability and braking ability. Steerability will be called the ability to keep the unit on course, steerability is characterized by course stability and manoeuvrability. The circulation manoeuvre determines the manoeuvrability of the craft. On the other hand, braking ability - stopping the unit at the shortest distance.

Overview of Standards and Criteria [6]. An overview of standards and criteria is given in Section 2, Table All the manoeuvres, except stopping, are to be executed on both port and starboard and averaged values are to be used for rated and non-rated criteria, e.g.:

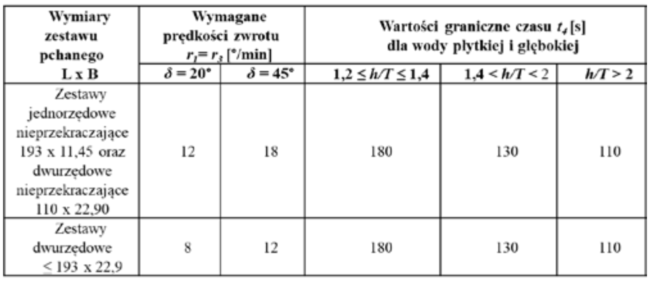
Table 4. Overview of Standards and Criteria [6]

Measure of Manoeuvrability	Criteria and Standard	Manoeuvre	IMO Standard	ABS Guide Requirement
Required for Optional Class Notation				
Turning Ability	Tactical Diameter	Turning Circle	TD<5L	Rated Rtd≥1
	Advance		Ad<4,5L	Not rated Ad<4,5L

The sailing and manoeuvring properties [8] should be confirmed during tests, at least:

- the ability to perform an evasive manoeuvre
- the ability to perform a turning manoeuvre

Table 5. Required turning speeds and time limits



Wymiary zestawu pchanego L x B	Wymagane prędkości zwrotu $r_1 = r_3$ [°/min]		Wartości graniczne czasu t_4 [s] dla wody płytkiej i głębokiej		
	$\delta = 20°$	$\delta = 45°$	$1{,}2 \leq h/T \leq 1{,}4$	$1{,}4 < h/T < 2$	$h/T > 2$
Zestawy jednorzędowe nieprzekraczające 193 x 11,45 oraz dwurzędowe nieprzekraczające 110 x 22,90	12	18	180	130	110
Zestawy dwurzędowe ≤ 193 x 22,9	8	12	180	130	110

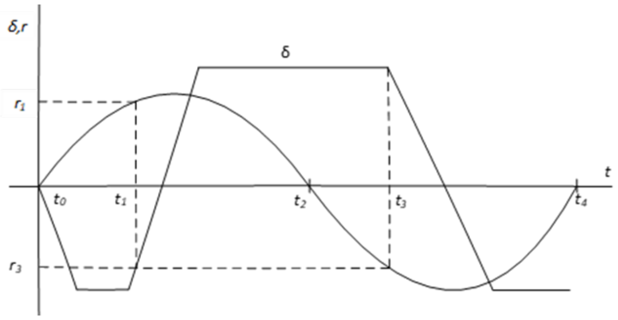


Figure 4. Evasive manoeuvre chart [8]

t_0 = start of avoidance manoeuvre
t_1 = time to reach the turning speed r_1
t_2 = time to reach the rate of return $r_2 = 0$
t_3 = time to reach the turning speed r_3
t_4 = turn speed time $r_4 = 0$ (end of evasive manoeuvre)
δ = rudder angle [°]
r = rate of turn [°/min].

5 UMG FIELD MODEL TESTS OF IMPROVING THE MANOEUVRABILITY OF THE UNIT

The UMG conducts research in the field of improving safety in inland waterway transport, improving manoeuvring properties - manoeuvrability of pushed vessels. A model of the bow control system using the lift force on the rotor was built. The existing vertical and retractable versions of rotor bow rudder [10][11] are not suitable for shallow water conditions, therefore the steering system of rotors integrated with the barge bow has been proposed.

5.1 *Model tests using hydrodynamic rotors*

The highest value of the lifting force was obtained for the water flow velocity of 2.6 m/s (9.36 km/h) and the rotational velocity of 170 rpm - corresponding to the limit values of the tested parameters. Increasing the rotational speed in the presented experiment did not result in a further increase in lift due to the separation of the flow and the appearance of vortices [1][2].

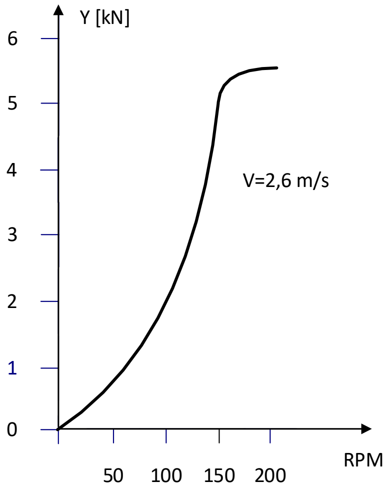


Figure 5. Lift generated by a rotor with a diameter of D=0.25 m and a height of L=1 m.

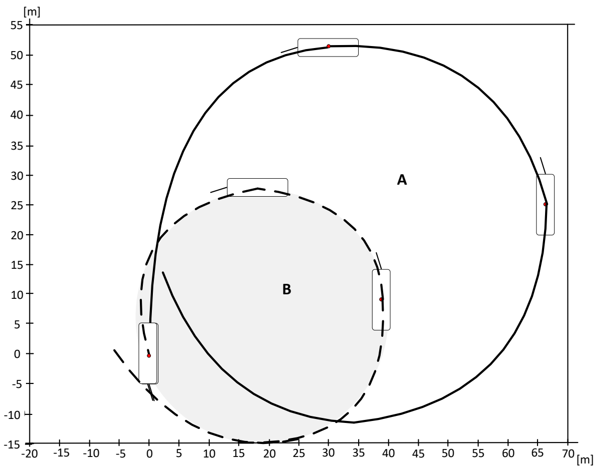


Figure 6. Comparison of circulation areas with rudder (10° starboard), rotors (300 turns) B and without rotors A

Simulations of the application of the bow hydrodynamic control system in narrow passages

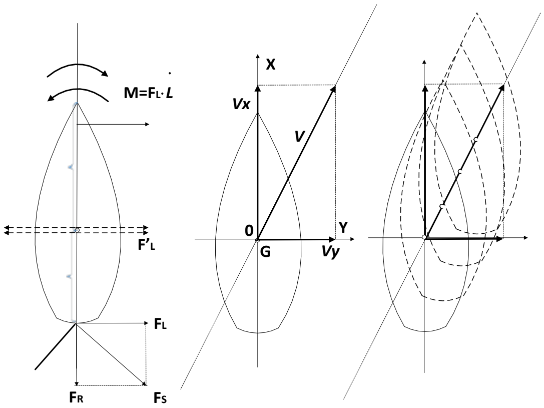


Figure 7. Lateral displacement of the ship due to the operation of the rudder and the bow hydrodynamic system
F_S –The hydrodynamic force acting on the rudder
F_L – Lift force
F_R – Rudder resistance

The estimated lift force generated on RC is 12 N (165 kN in real scale) greater than rudder-generated lift force [9].

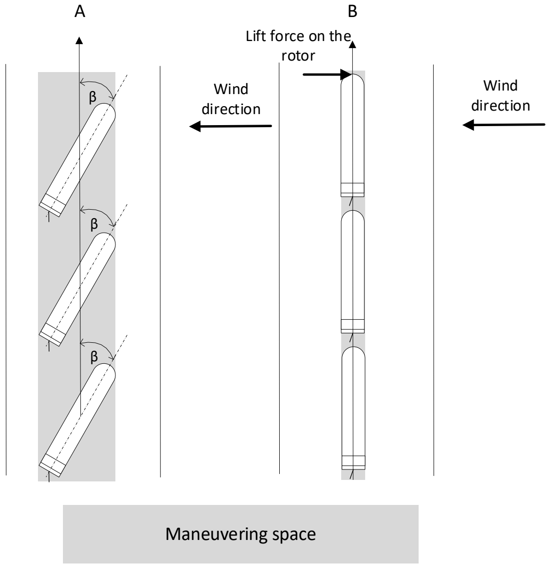


Figure 8. Comparison of manoeuvring space for a vessel in the wind without (A) rotors and using (B) rotors

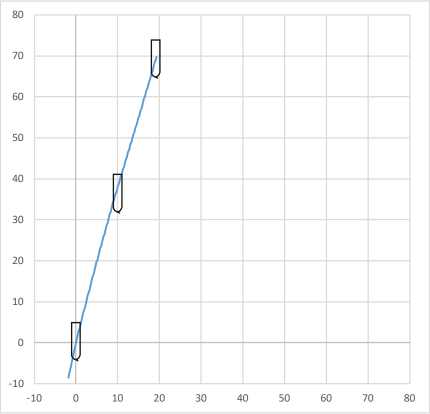


Figure 9. The trajectory of the model plotted during the steady course trial [9]

In order to increase the manoeuvrability of the unit, UMG proposed a coupling connecting the pusher with the barge

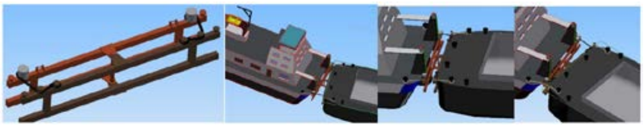


Figure 10. UMG solution of the coupling connecting the pusher with the barge [1]

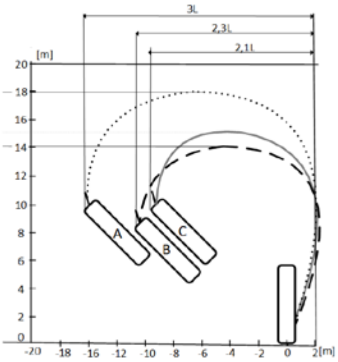


Figure 11. Turning circle of push barges: (A) trial - turning to port using the rudder - 35° (B) trial - turning to port using the rudder - 35° and bow rotors (C) trial - turning to port using the rudder - 35°, bow rotors and dynamical coupling system [PMR]; L – pushed model length [1].

Limited manoeuvrability, large manoeuvring space - can be a collision of two ships presented below: the 100-meter coastal freighter Siderfly collided with the 116-meter gas carrier Coral Ivory just a few miles past the canal locks at Brunsbuttel [12].

6 CONCLUSIONS

The simulations and model tests of the bow steering system using the Magnus Effect presented in the article significantly improve the manoeuvring properties of inland waterway vessels. The use of the Magnus Effect in the bow steering system significantly reduces the vessel's circulation diameter. It allows you to steer the vessel in the wind without the drift angle, and at the same time enables the evasive manoeuvre by limiting the manoeuvring space to the width of the manoeuvring vessel.

It can be said that the improvement of the manoeuvring properties of the vessel through the use of the Magnus Effect improves the level of safety in inland navigation.

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