

# Enhanced free-running manoeuvring tests of inland vessels in model scale

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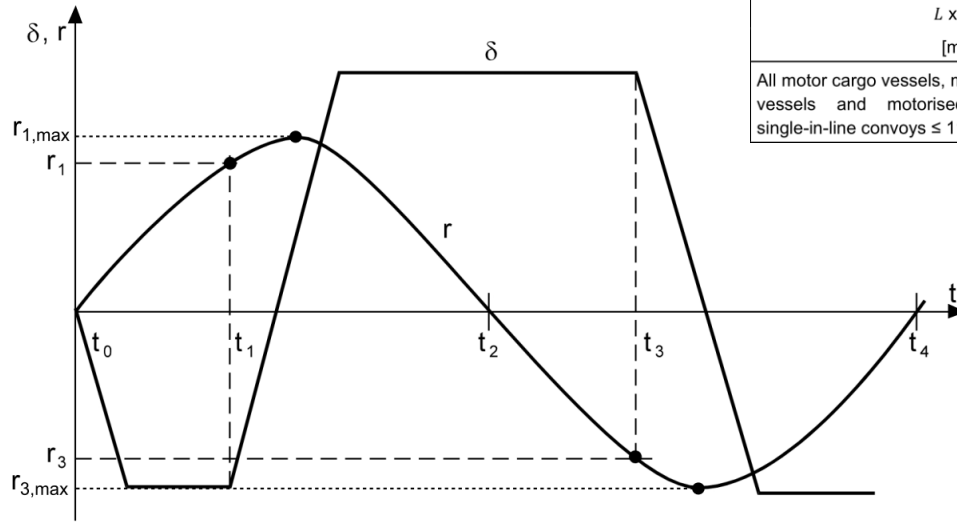
## Inland navigation

- Enormous process of transformation
  - Emission reduction and decarbonisation
  - Automation
  - Adaption to climate change
  - Complex supply chains
- Heterogeneous fleet with a variety of ship designs
- Permanently changing boundary conditions
- Differing operating conditions

 High relevance of inland vessel manoeuvring

- Motivation
- Objectives
- Experiments
  - Test setup
  - Ships
- Results
- Conclusion and Outlook

- Direct determination of the manoeuvring behaviour in model scale
  - Capacity for taking evasive action (ES-TRIN, Article 5.09)
  - Further development of criteria



| Dimensions of vessels or convoys<br>$L \times B$<br>[m]                                                                                    | Required turning speed<br>$r_1 = r_3$ [°/min] |                     | Limit values for the time $t_4$ (s) in shallow and deep water |                    |           |
|--------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------|---------------------|---------------------------------------------------------------|--------------------|-----------|
|                                                                                                                                            | $\delta = 20^\circ$                           | $\delta = 45^\circ$ | $1,2 \leq h/T \leq 1,4$                                       | $1,4 < h/T \leq 2$ | $h/T > 2$ |
| All motor cargo vessels, motor tankers, passenger vessels and motorised floating equipment; single-in-line convoys $\leq 110 \times 11,45$ | 20°/min                                       | 28°/min             | 150 s                                                         | 110 s              | 110 s     |

- Provision of reference tests
  - Comparison with CFD calculations
  - Comparison with ship handling simulations
- Investigation of complex ship hydrodynamics
  - Determination of optimisation potentials
  - Understanding of complex interactions
- Flexible but effective test concept with high accuracy
- [Link to practical automation technology](#)

 Free-running manoeuvring tests

# Test setup I

- Optical motion tracking system
  - Relative position and velocity to carriage (x-coordinate)
  - Conversion of position to artificial full-scale GPS-coordinates
  - Conversion of ship velocity to full-scale values (including Kalman filter)
- Fibre-optic gyroscope
  - Conversion of yaw rate to full-scale values



# Test setup II

- Data transmission via local WLAN
- Actuated rudders
  - Asymmetrical or symmetrical control
  - Rotational speed as specified in full-scale and converted to model scale
- Propeller dynamometer and duct forces
- (Future: Rudder forces)



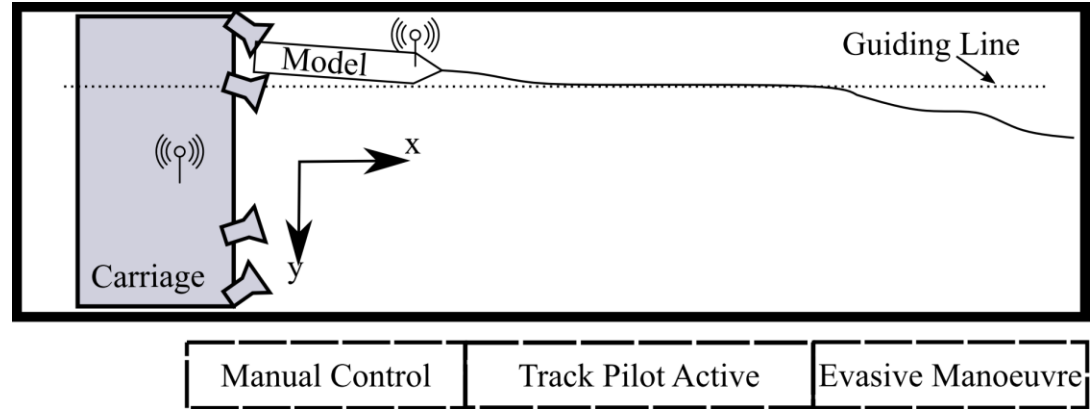
# Test setup III

- Use of a real track guidance assistant
  - Conversion of the input data to NMEA 0183 data packets
  - Also includes a rate of turn controller (river pilot)
  - Customer-specific extension for the automation of manoeuvres
- Four modes of operation
  - 1) Manual steering
  - 2) ROT control
  - 3) Track control
  - 4) Manoeuvre automation
- Combined data acquisition



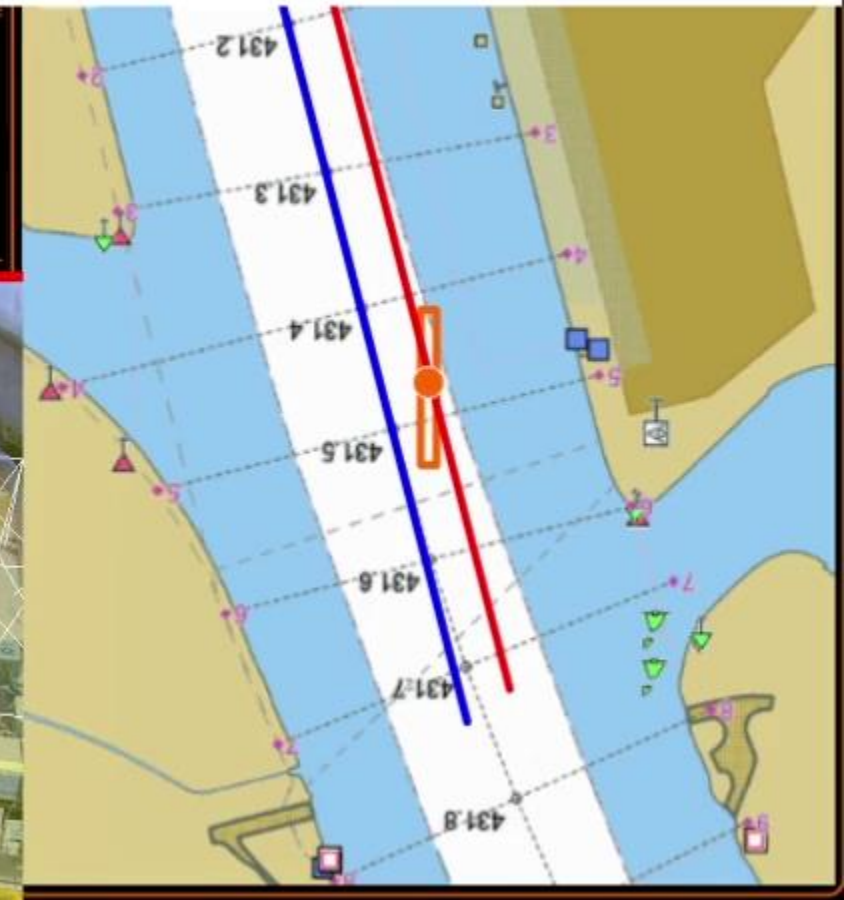
# Test procedure I

- 1) Manual steering to desired position and coarse adjustment of velocity
- 2) Activation of track pilot and fine adjustment of velocity
- 3) Start of manoeuvre
- 4) Manual deceleration





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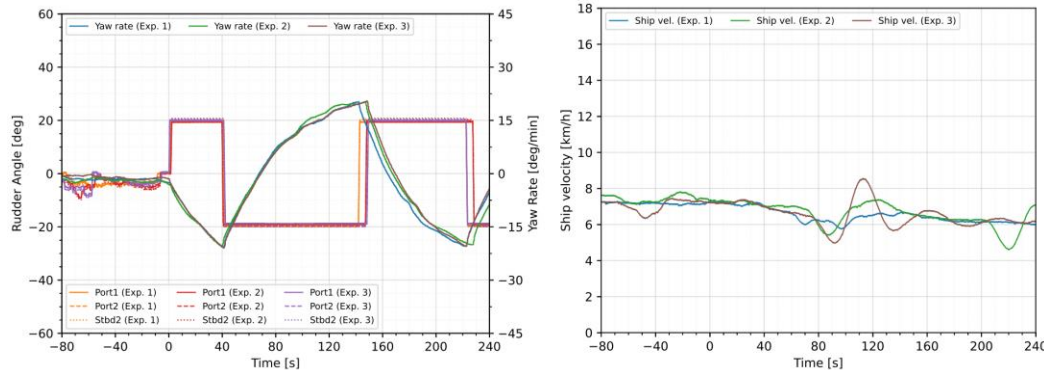


# Ships

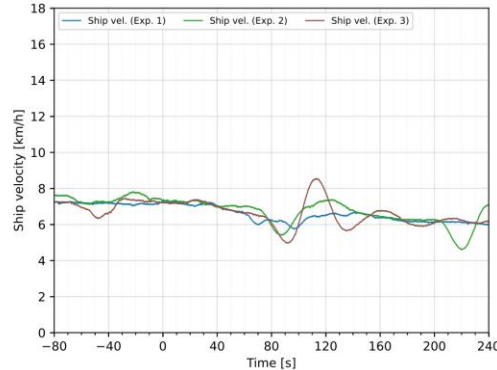
| Parameter       | Ship 1         | Ship 2           |
|-----------------|----------------|------------------|
| CEMT-class      | VIb            | Va               |
| Ship length     | 135 m          | 110 m            |
| Ship breadth    | 14.15 m        | 11.45 m          |
| Ship draught(s) | 2.6 m<br>1.7 m | 2.8 m            |
| Propulsion      | Twin-propeller | Single-propeller |
| Main engines    | 2 × 1030 kW    | 1326 kW          |
| Steering        | Twin-rudder    | Twin-rudder      |
| Cargo           | Container      | Liquid bulk      |



# Results (Ship 1) I

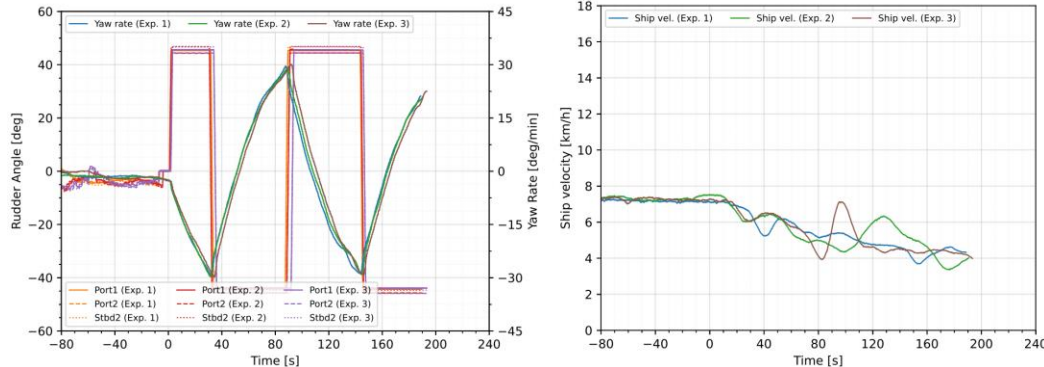


(a) Rate of turn in full scale and rudder angle

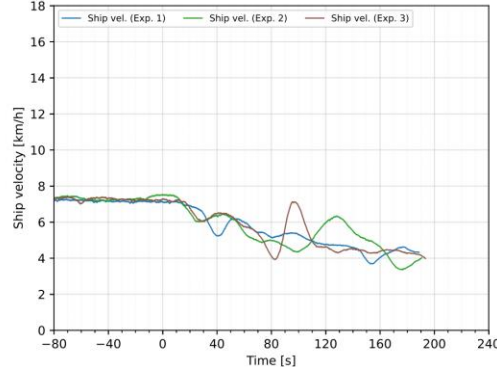


(b) Ship velocity in full scale

Evasive manoeuvre 20-20  
 $h/T=1.5$ ,  $T=1.7$  m  
 $V_S=7.3$  km/h



(a) Rate of turn in full scale and rudder angle



(b) Ship velocity in full scale

Evasive manoeuvre 45-28  
 $h/T=1.5$ ,  $T=1.7$  m  
 $V_S=7.3$  km/h

# Results (Ship 1) II

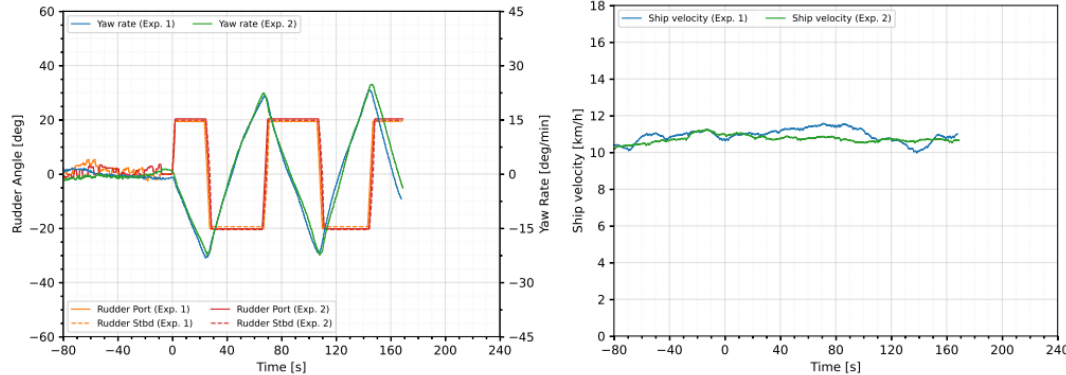


| $h/T$ [-] | $V_S$ [km/h] | $\sigma(V_S)$ [%] | Manoeuvre | No. tests | $\bar{t}_4$ [s] | $\sigma(t_4)$ [%] | $\bar{\Delta}_r$ [°/min] |
|-----------|--------------|-------------------|-----------|-----------|-----------------|-------------------|--------------------------|
| 7.34      | 6.9          | 2.71              | 20-20     | 1         | 173.7           | -                 | 0.1                      |
|           |              |                   | 45-28     | 1         | 114.3           | -                 | 0.2                      |
| 2.0       | 7.0          | 0.77              | 20-20     | 2         | 149.0           | 3.56              | 0.2                      |
|           |              |                   | 45-28     | 2         | 106.0           | 0.59              | 0.2                      |
| 1.5       | 7.3          | 3.10              | 20-20     | 3         | 166.9           | 1.39              | 0.1                      |
|           |              |                   | 45-28     | 3         | 108.5           | 1.74              | 0.3                      |
| 1.2       | 6.1          | 1.52              | 20-10     | 2         | 103.5           | 3.41              | 0.1                      |
|           |              |                   | 45-18     | 3         | 92.2            | 1.56              | 0.2                      |

Evasive manoeuvres  
T=1.7 m

- Speed accuracy needs to be improved (currently manual)
- Evaluation of  $t_4$  is possible in good quality, but only valid if the criteria are met ( $V_S=13$  km/h,  $T_{\min}=70\%$ )
- The “overshooting rate of turn”  $\Delta_r$  is very small

# Results (Ship 2) I



(a) Rate of turn in full scale and rudder angle

(b) Ship velocity in full scale

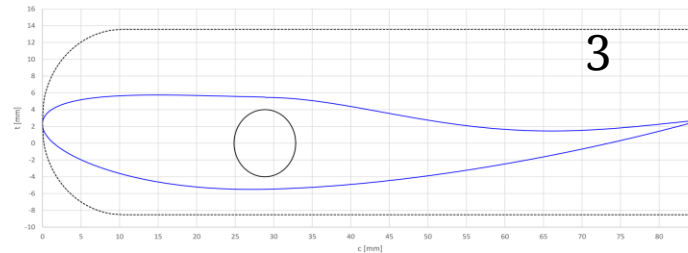
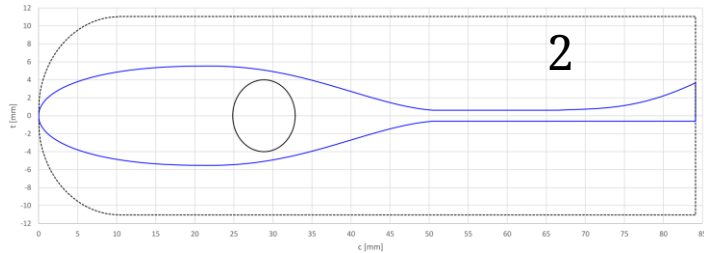
Evasive manoeuvre 20-20  
 $h/T=1.3$ ,  $T=2.8$  m  
 $V_S=11.1$  km/h

➤ Equally good agreement of repetition

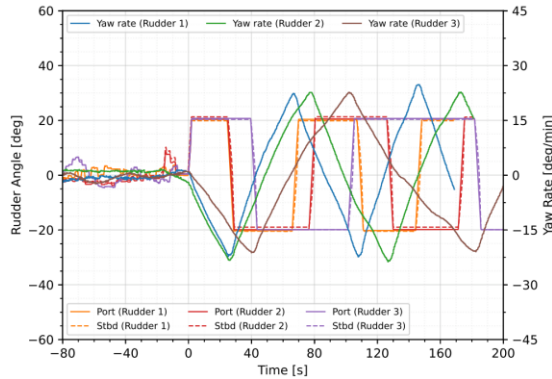
# Results (Ship 2) II

## Testing of different rudder profiles

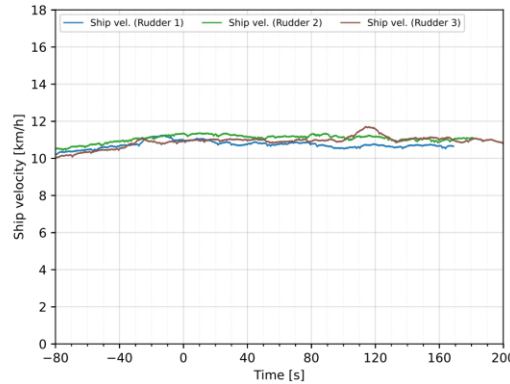
| Rudder | Profile                   | Rudder height<br>[mm] | Chord length<br>[mm] | Profile thickness<br>[mm] | Height-length-ratio<br>[-] |
|--------|---------------------------|-----------------------|----------------------|---------------------------|----------------------------|
| 1      | Schilling type (modified) | 105.9                 | 112.4                | 16.4                      | 0.94                       |
| 2      | Schilling type            | 105.9                 | 84.1                 | 11.1                      | 1.26                       |
| 3      | Curved centreline         | 105.9                 | 84.1                 | 11.1                      | 1.26                       |



# Results (Ship 2) III



(a) Rate of turn in full scale and rudder angle



(b) Ship velocity in full scale

Evasive manoeuvre 20-20  
 $h/T=1.3$ ,  $T=2.8$  m  
 $V_S=11.1$  km/h

- The effects of different rudder profiles can be analysed
- The comparison shown is not entirely fair (different rudder dimensions)

# Conclusion

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- The concept shown allows free-running manoeuvring tests in the towing tank with an integrated real track guidance assistant
- Semi-automated tests and parameter studies can be carried out to determine the manoeuvring characteristics
- The potential repeatability is already quite good
- There are currently restrictions due to the manual control of the propeller rotation rate (ship speed)

- Further investigation of repeatability
  - Scale effects
  - Tank effects
    - History (residual fluid motions)
    - Influence of tank walls
  - Adapted criteria for assessing the manoeuvring behaviour at slow speeds in restricted fairways
  - Study on control parameters (river pilot and track pilot)
- ➡ Fuel-efficient sailing

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Thank you very  
much for your  
attention!

