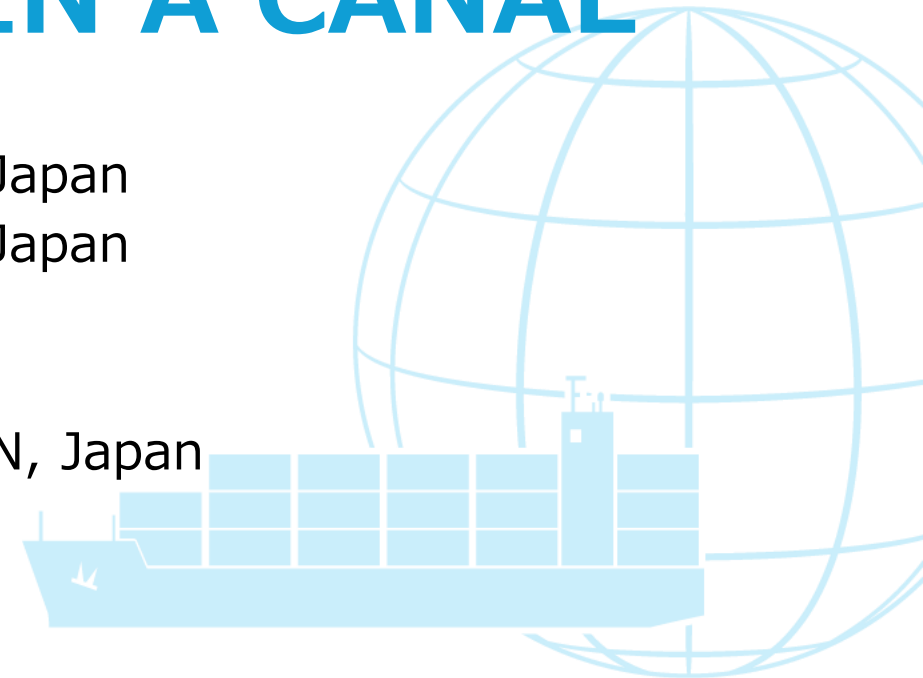


VISCOUS CFD SIMULATION OF PMM TESTS IN SHALLOW WATER AND IN A CANAL

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Introduction



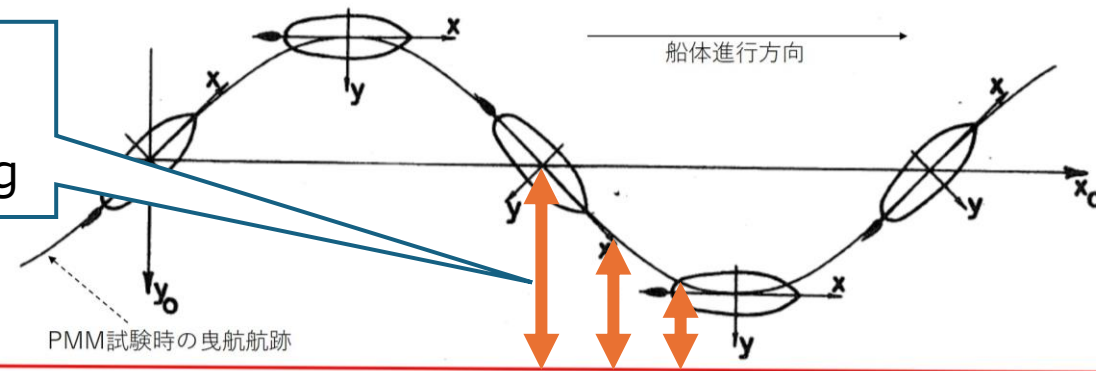
- The accident involving a large container ship in the Suez Canal has highlighted the importance of ensuring safe navigation within the canal.
- There are various conditions to consider... this study focuses on the case of one large ship navigating a one-way canal.
- The mathematical model of hydrodynamic force to construct a manoeuvring simulation is necessary.
- Fujino(1968, 1970)
 - The hydrodynamic force expression as the sum of the linear terms of the drift angle, the turning angular velocity, and the lateral displacement from the center of the waterway
 - By PMM tests, steady oblique towing tests, and a straight-line test with changed lateral positions.
 - Some simplifications have been made, and it is questionable whether the calculation is sufficiently precise.
(The derivative of drift angle obtained from the steady oblique towing test $\neq$ from the PMM test)
- Precise formulation has not been completed.

Introduction



- PMM test in a waterway is a way to obtain the hydrodynamic derivatives
- Problem comes from the characteristic of the PMM test:
The distance from the side wall also varies periodically (together with drift or yawing motion)
-> difficult to properly evaluate or remove the side wall effect from PMM test result
- The aim of this study: to examine **the influence of side walls on PMM test results**
- CFD was selected as the tool (already verified in steady test within a canal)
- Numerical simulations of PMM tests, which is an unsteady test, was conducted and results were evaluated

During the pure yawing motion, the distance from the side wall is also varying

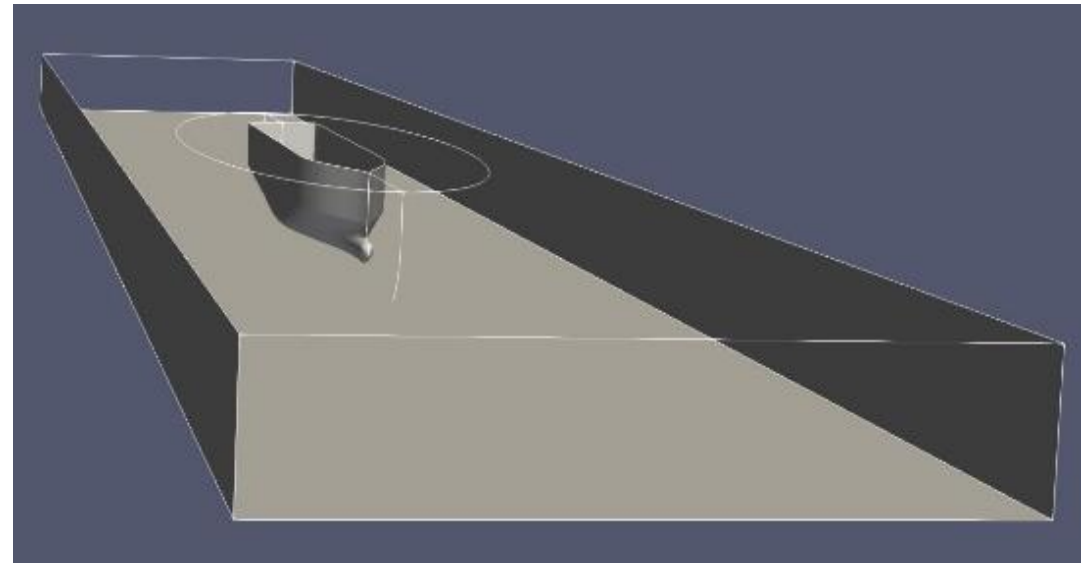
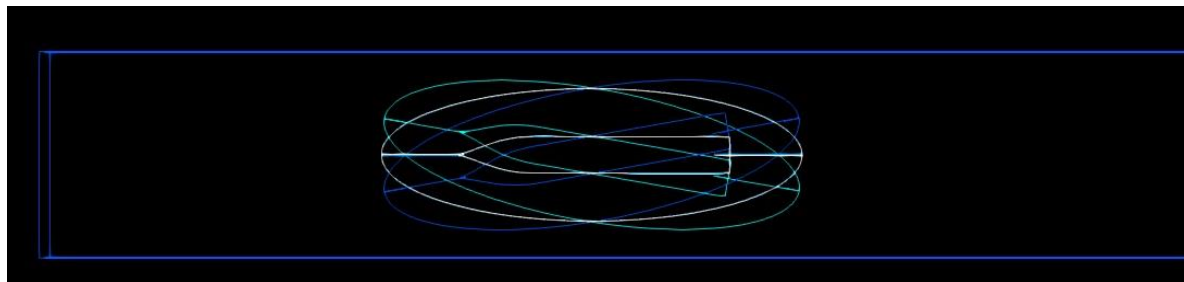


Computational Method



The in-house Reynolds-averaged Navier Stokes (RaNS) CFD code NAGISA

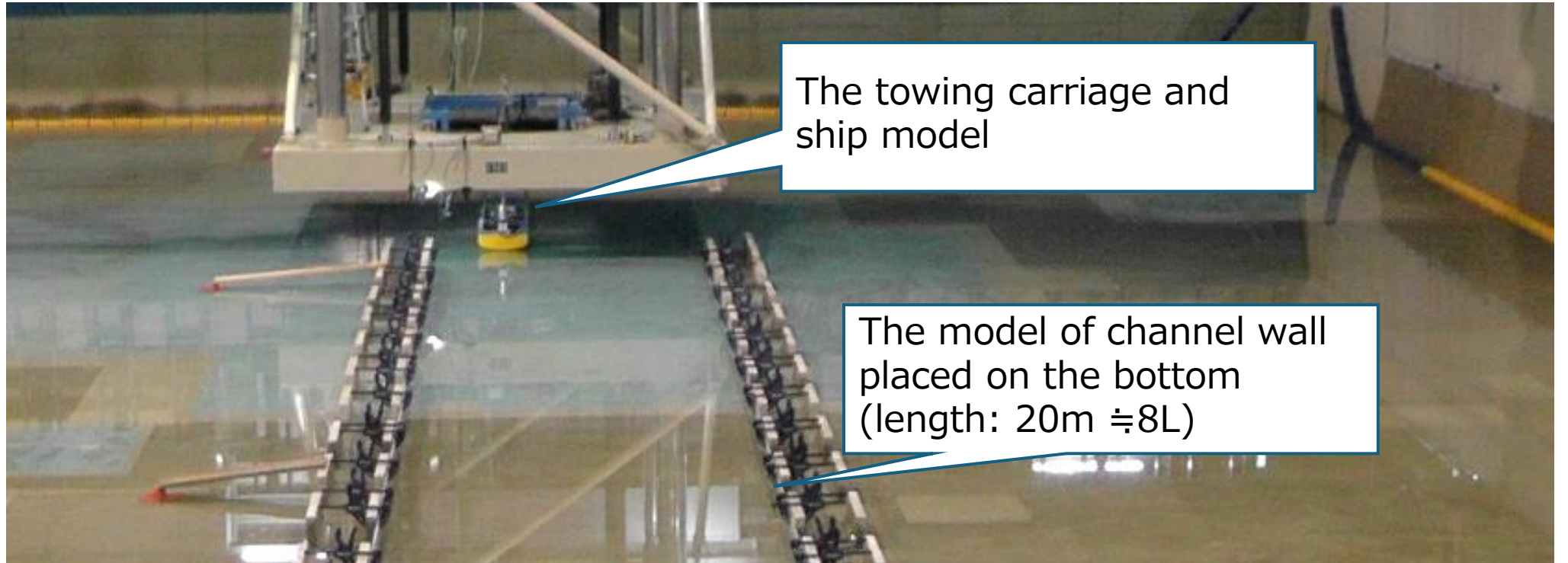
- Finite volume method
- The multi-block and multi-domain computation with overset structured grid
- Coupling unsteady flow computation and motion equation (pitch and heave)
- Turbulence model: EASM algebraic model
- Free surface model: single-phase level-set method
- A simplified propeller model



Model Experiments

Conducted at Seakeeping and Manoeuvring Basin of Kyushu University

- Length: 38.8m, width: 24.4m, depth: 2.0m (bottom precision: $\pm 2\text{mm}$)
- The X-Y towing carriage with turn table is equipped
- Sampling rate of forces: 100Hz (LPF applied: cut-off freq. 5Hz)
- Position and force data were synchronized after measurement



Test Ship



- KCS container ship (model length: 2.5m)
- Rudder and propeller are equipped (without bilge keels)
- Turbulence stimulation: 5%L from F.P.
- Radius of gyration k_{yy}/L : assumed to be 25%L

	Full scale	Model Exp.	CFD
L (m)	230	2.5	1 (nondim)
d (m)	10.8	0.117	0.047 (nondim)
U (m/s)	4.116	0.429	1 (nondim)
Fr	0.087	0.087	0.087
Re	7.96e8	9.42e5	9.42e5

Computational Conditions



- Computational grids: 3 blocks (hull, rudder, external region)
- Computational domain (depth and width are the same as experiments)

Type	Deep	Shallow	Canal
Water Depth	1.22L	0.0696L (h/d=1.48)	0.0696L (h/d=1.48)
Domain Width	2.74L	2.74L	0.7826L
Domain Length	5.27L	5.27L	5.27L
Num. of Cells	7,931,904	7,017,984	6,089,728

- Propeller revolution is decided from the self-propulsion test in steady straight course

	Deep	Shallow	Canal
Experiment (rps)	N/A	6.8	7.1
CFD (converted to rps)	6.5	6.7	7.1

Computational Conditions



Two PMM test condition

1. large-amplitude pure swaying motion

sway amplitude= $0.123L$ (300mm in model scale), period=25s in model scale

2. pure yawing motion condition

nondimensional yaw rate amplitude =0.1 , period=25s in model scale

- PMM Motions around the centerline of the canal
- The computational grid is fixed on the inertial coordinate system moving at the initial velocity
- Period is set so that the travel distance per cycle is within the length of the channel in the model basin

Results and Discussion



● Restricted Water Effects on Hydrodynamic Forces and Moment (Pure Swaying Motion)

Longitudinal force:

Cyclic component (2nd or higher order derivatives) increases in the shallow and canal conditions

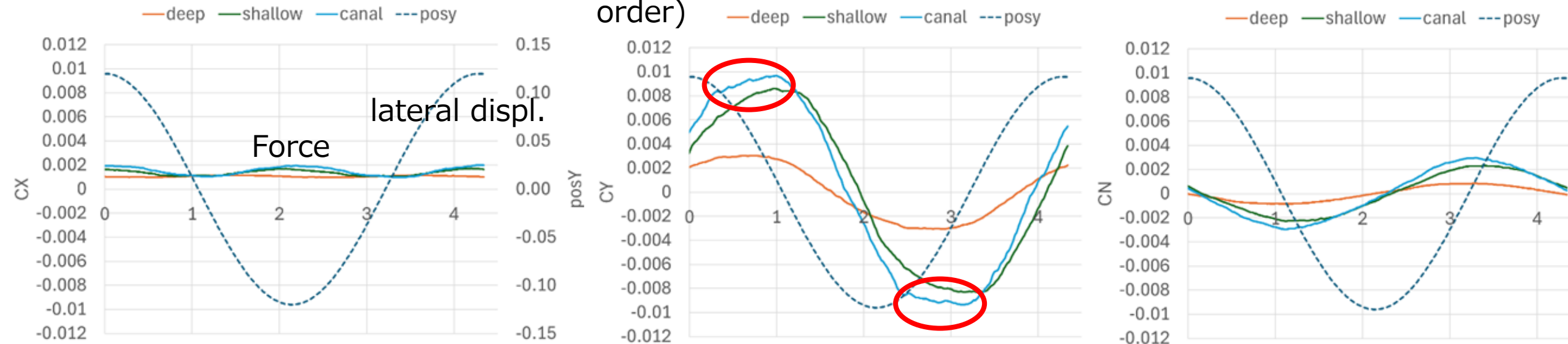
Lateral force:

The amplitude increases in shallow and canal conditions (restricted water effect)

Waveform changes near the wall (side wall effect / higher order)

Yawing moment:

The amplitude increases in shallow and canal conditions (restricted water effect)



There are both global and local effects and the local effects may depend on the distance of the ship from the wall

Results and Discussion

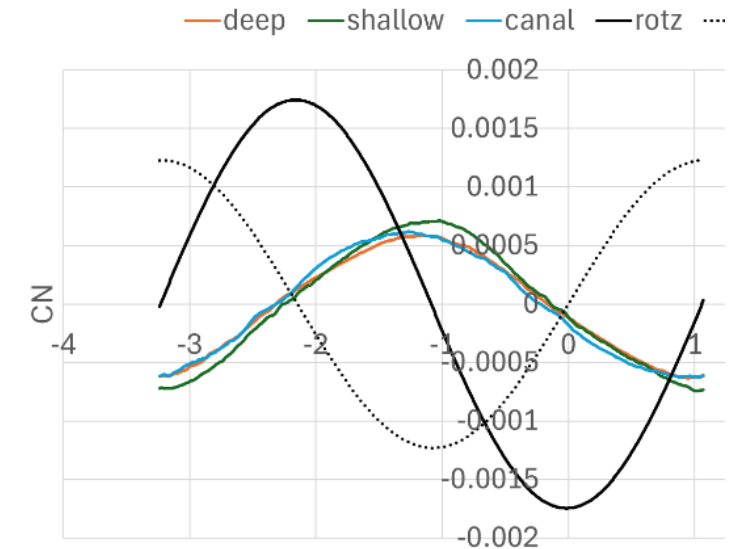
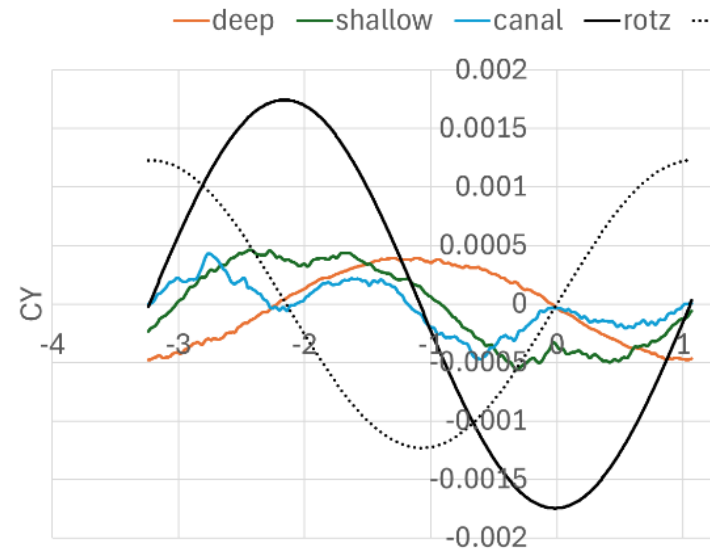
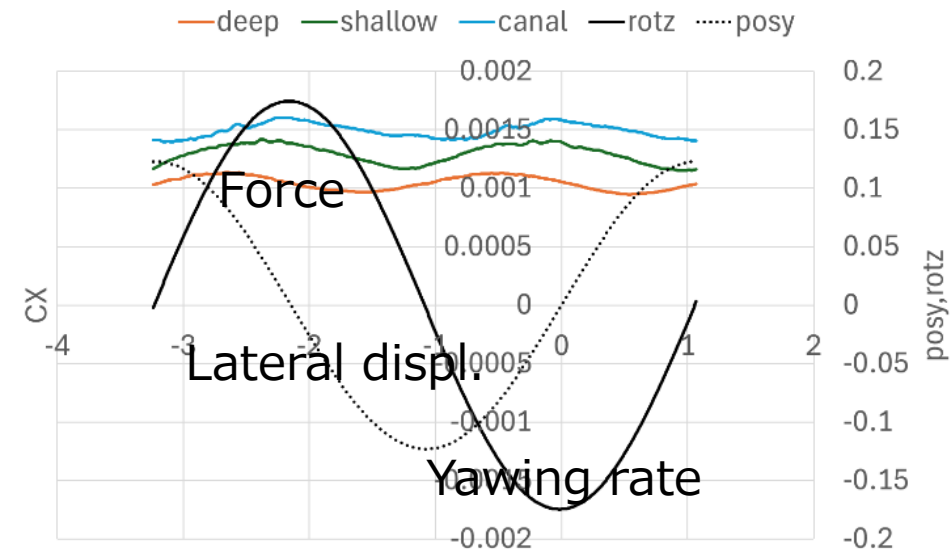


● Restricted Water Effects on Hydrodynamic Forces and Moment (Pure Yawing Motion)

Longitudinal force:
Steady resistance component increases in the shallow and canal conditions (restricted water effect)

Lateral force:
Small differences in amplitude
Higher order components exist (the error may be large)

Yawing moment:
Small differences

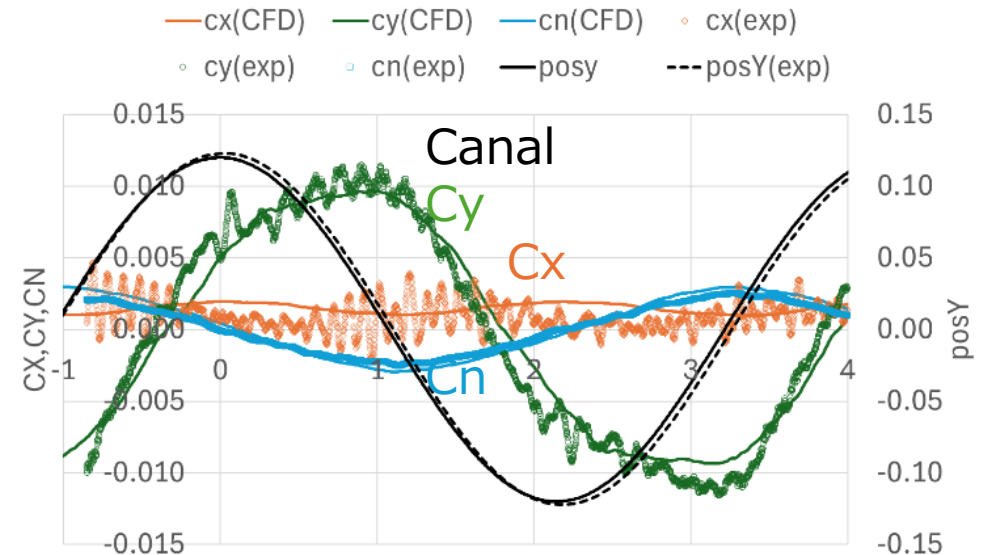
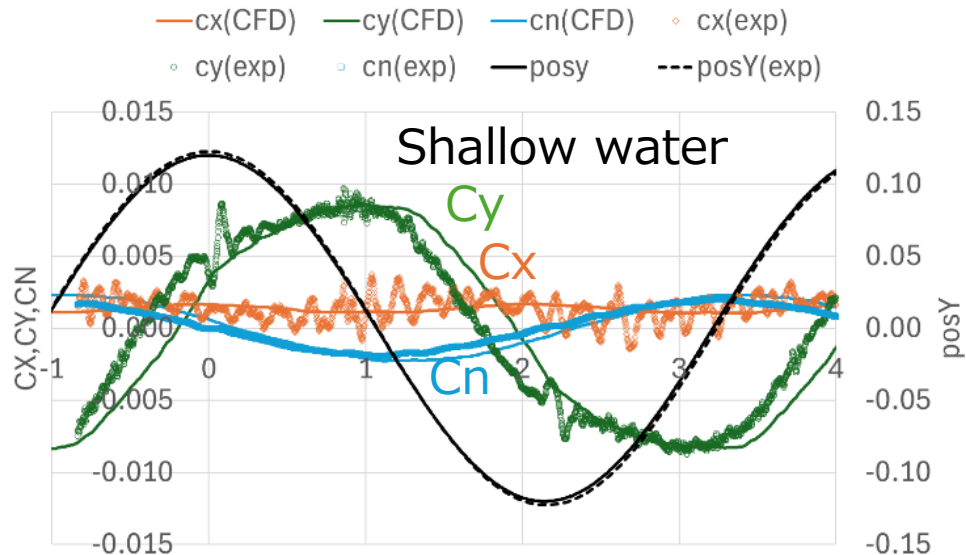


Results and Discussion



- Computed and Measured Results (Pure Swaying Motion) in shallow water and canal
Computed and measured hydrodynamic forces and moment are consistent over time (slight error in phases)

*Experiment in deep water is not conducted yet



Results and Discussion

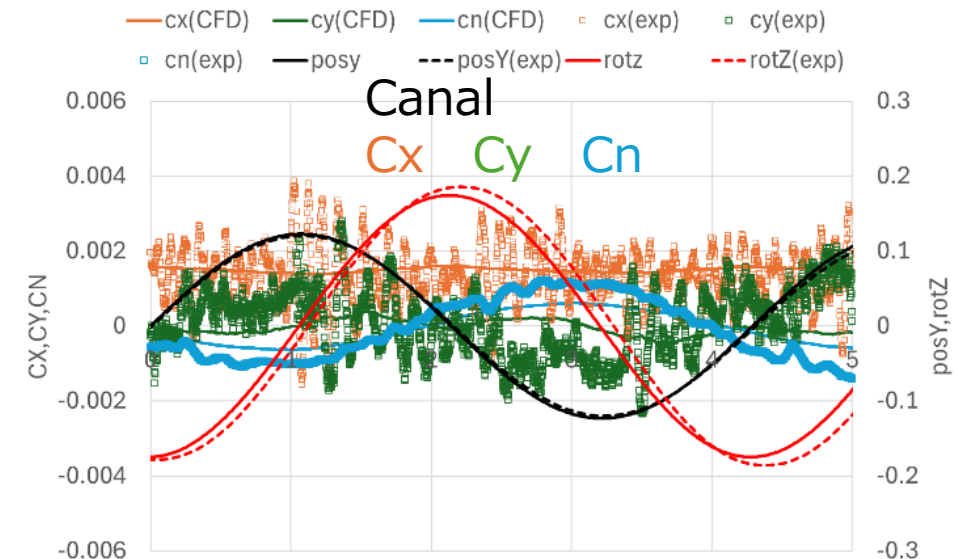
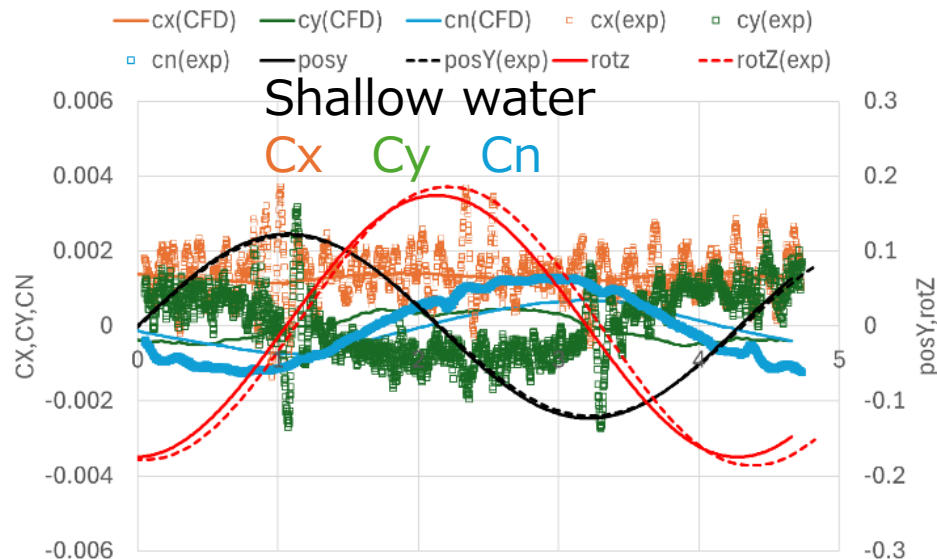


- Computed and Measured Results (Pure Yawing Motion) in shallow water and canal

Small errors are observed between ordered and measured yawing rate

Computed and measured results have errors in both amplitude and phase

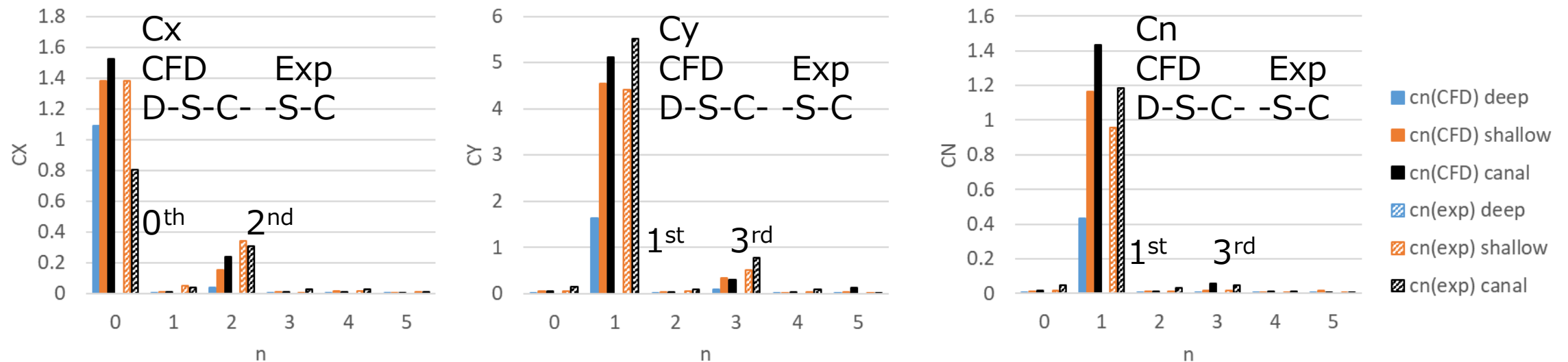
- Lack of precision due to small CY values in pure yawing motion
- The majority of the measured forces are inertial forces (to be subtracted), not hydrodynamic forces
- The canal length may be insufficient for the PMM motion cycle, and the influence of the channel end may have remained



Results and Discussion



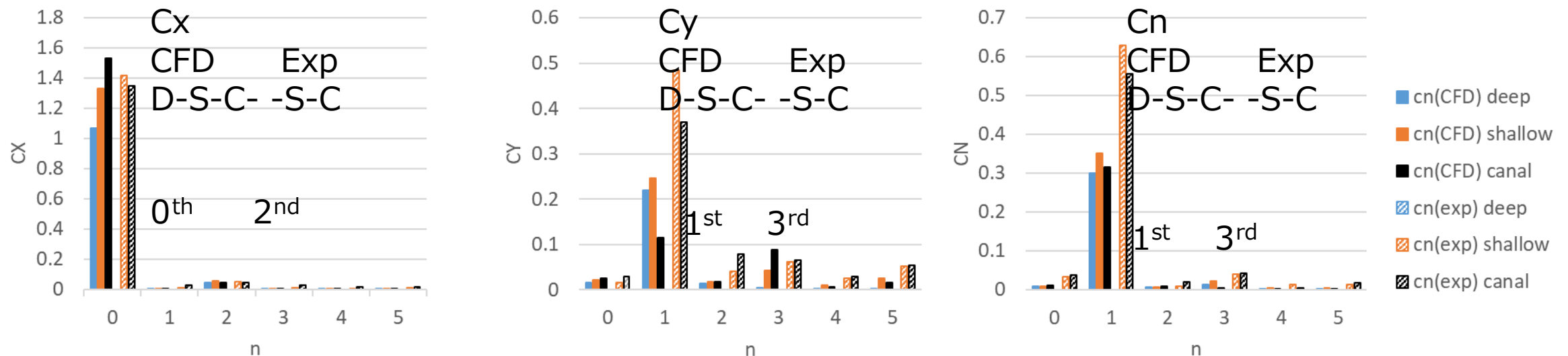
- PMM Test Fourier Analysis (Pure Swaying Motion)
- C_x : 0th and 2nd order coefficients, C_y , C_n : 1st and 3rd order coefficients (reasonable)
- The 4th and higher coefficients do not make a significant contribution
- Computed and measured results are in good agreement



Results and Discussion



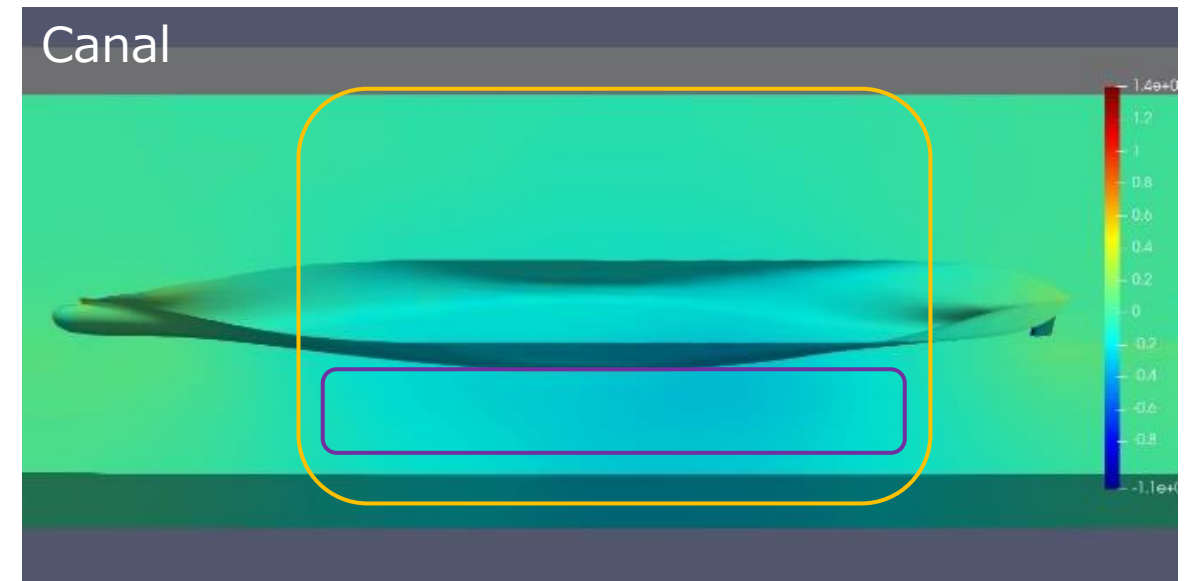
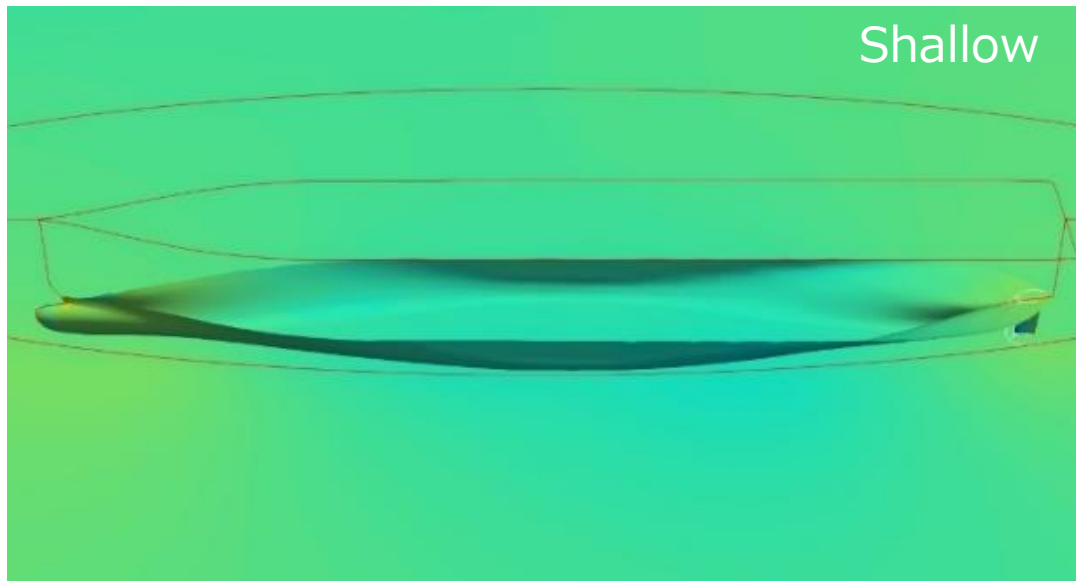
- PMM Test Fourier Analysis (Pure Yawing Motion)
- The coefficient itself is small, making it difficult to determine whether it is significant.
- There is room for improvement in the accuracy of the pure yawing test



Results and Discussion



- Pressure Distribution at the moment when the hull is closest to the left wall in pure swaying motion
 - overall tendency for pressure to decrease around the center of the ship (blockage effect)
 - the pressure drop between the portside of the ship and the side wall of the canal is particularly pronounced (local interference)
- Further research is necessary to properly analyze PMM tests in canals



Conclusions



The PMM tests in-channel as a means of obtaining a manoeuvring hydrodynamic force necessary for simulating manoeuvring motions in narrow waterways were investigated using CFD and tank tests. As a result, the following was found.

- For the pure swaying test, the results of the CFD and tank test show good agreement in terms of the Fourier coefficients and time series data.
- For the pure yawing test, the Fourier coefficients of the CFD and tank test are of the same order of magnitude, but the agreement in time series data is lower than for pure swaying case.
- The pure yawing test is difficult to ensure accuracy in terms of experimental measurements.
- In addition to the overall changes in flow velocity and pressure due to blockage effects, there is also local interference between the hull and sidewall, and further research is needed on analysis methods for PMM tests in waterways.

Consequently, viscous CFD can be used to simulate the unsteady hydrodynamic forces acting on a ship undergoing unsteady motion in a narrow waterway.

Thank you for your attention!

Acknowledgements:

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