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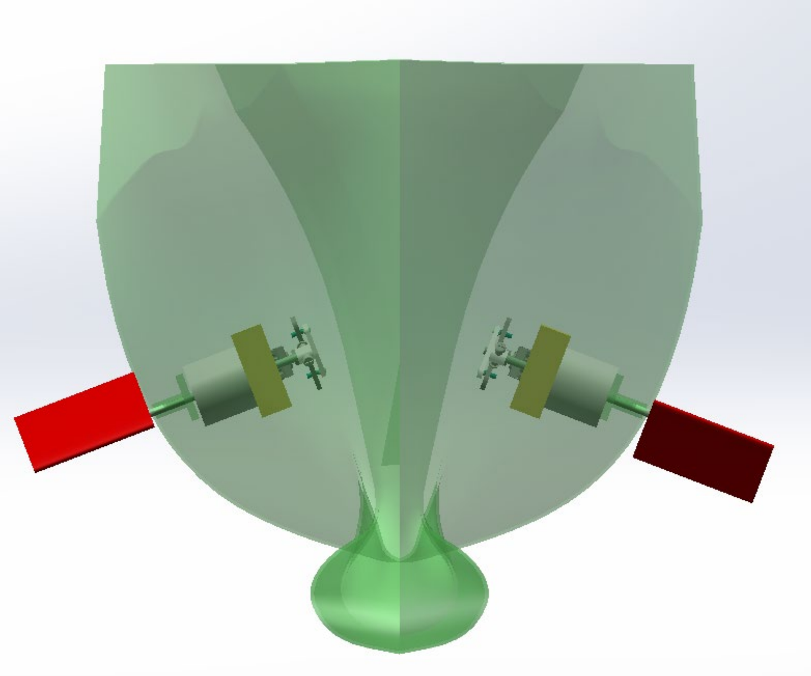
A predictive controller for joint pitch-roll stabilization

Key words:

Active fins, Joint pitch-roll stabilization, Predictive controller, Ship motion and hydrodynamic force prediction (SMHFP) controller



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Stabilization devices

Bilge keels ; rudder ; water tanks ; gyro-actuators ; fins

The forward speed is higher than 10~15knots, active fins are the most effective stabilizer (Perez, 2005).

Fins for roll stabilization

- Stabilizing fins have been widely studied since the 1950s, with most papers related to the reduction of roll motion.
- A large proportion of modern ships is equipped with active fins for stabilization.

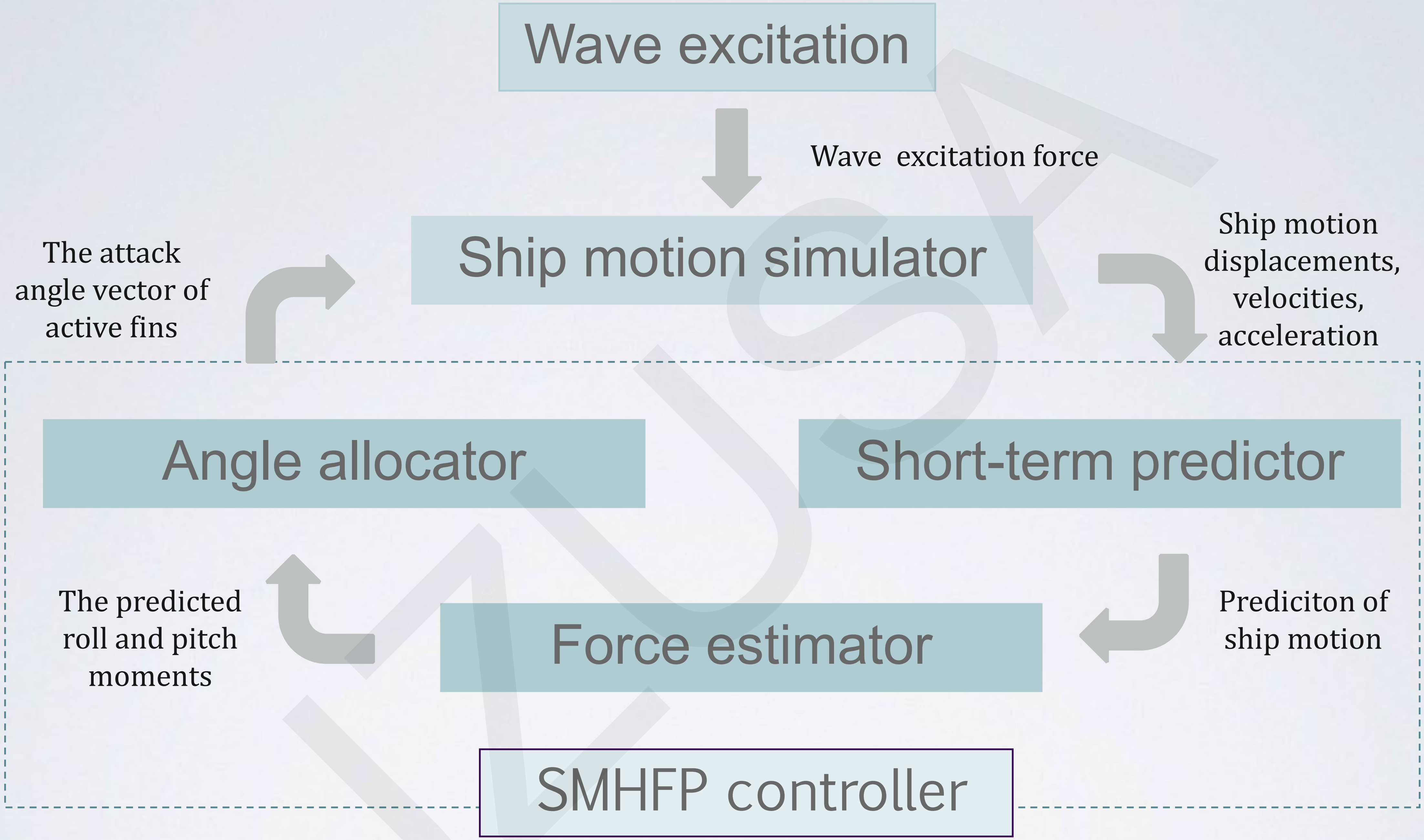
Fins for pitch stabilization

- Compared to anti-rolling, study on anti pitching has attracted relatively little interest.
- Active fins provide a relatively efficient way for anti pitching.

Fins for joint pitch-roll stabilization

- Roll and pitch motions were stabilized simultaneously by using two pairs of stabilizing fins. (Kim et al. 2012).
- The proposed controller is developed on the basis of ship motion and hydrodynamic force prediction (SMHFP).

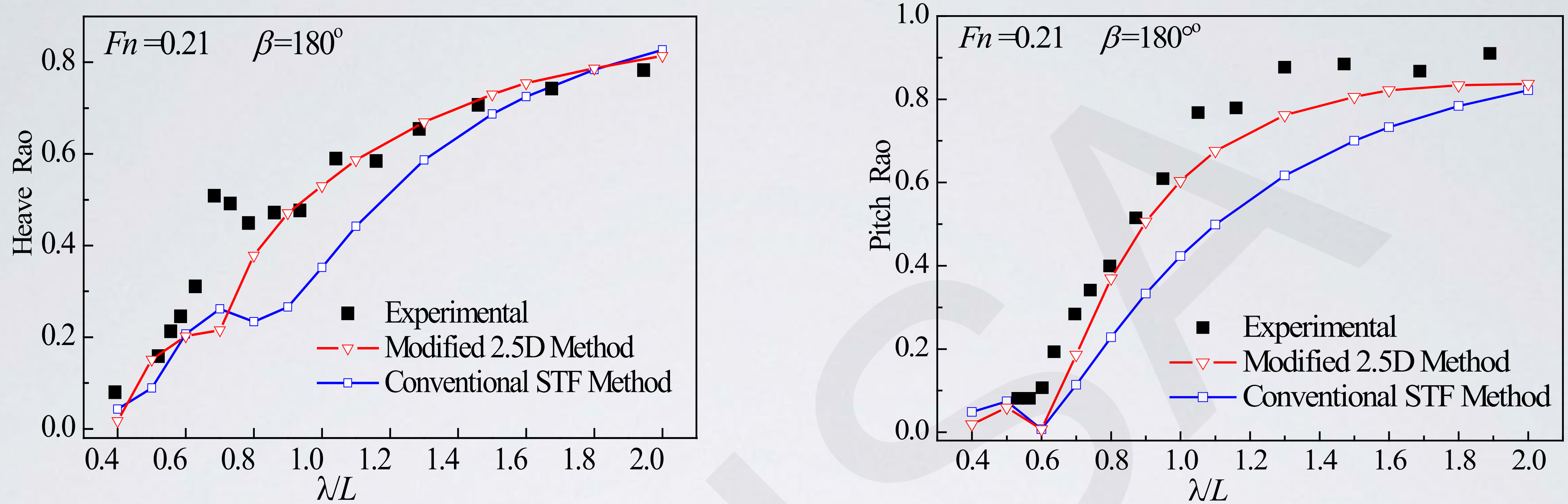
Methodology of SMHFP controller



The SMHFP controller consists of a short-term predictor, a force estimator and a fin angle allocator.

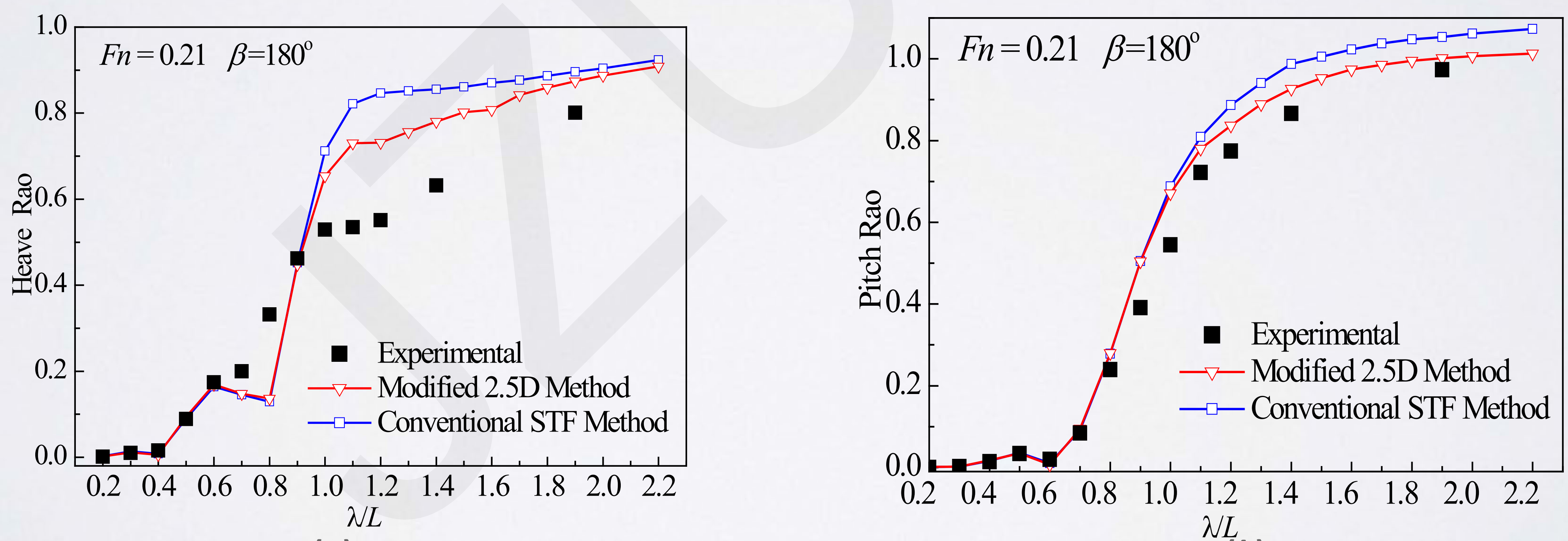
- The short-term predictor is used to forecast the ship motion.
- The force estimator evaluates incoming external hydrodynamic forces by applying the dynamic equilibrium between the external forces and the predicted ship motions.
- The fin angle allocator specifies attack angles for stabilizing fins according to the predicted hydrodynamic forces

Validation of the ship motion simulator



(*a*) (*b*)

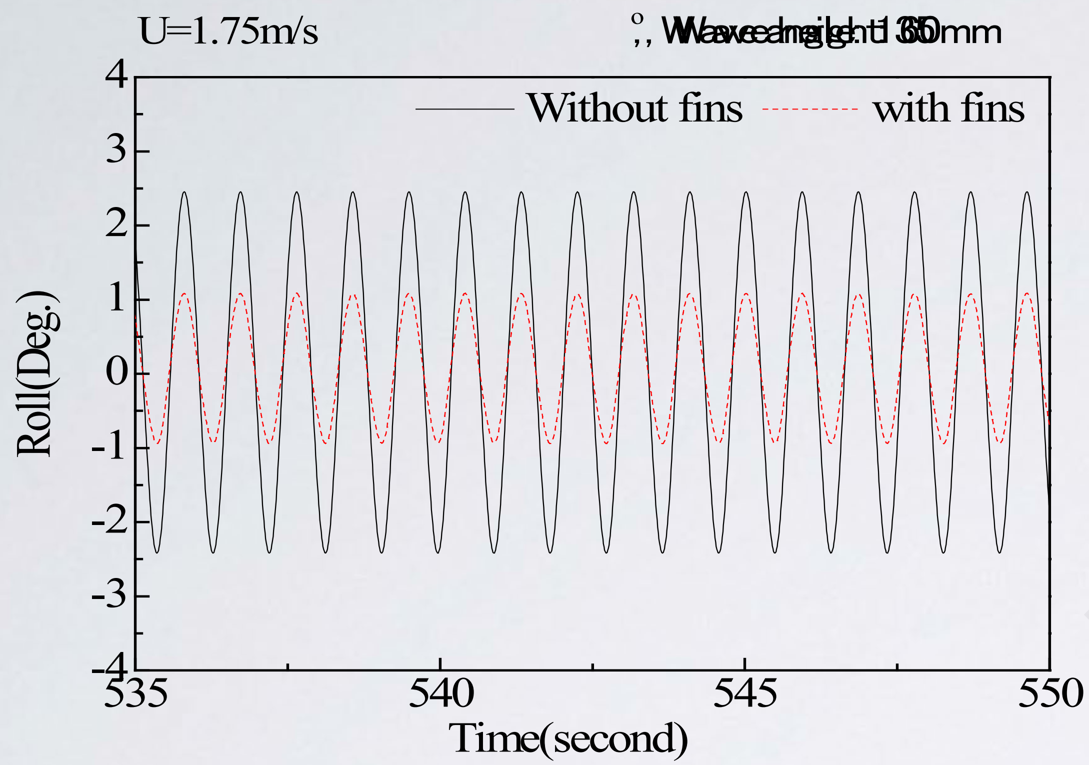
Figure 1 (*a*) Heave and (*b*) pitch RAOs of the Warship model: Froude number F_n=0.21, head sea with wave slope of 0.02.



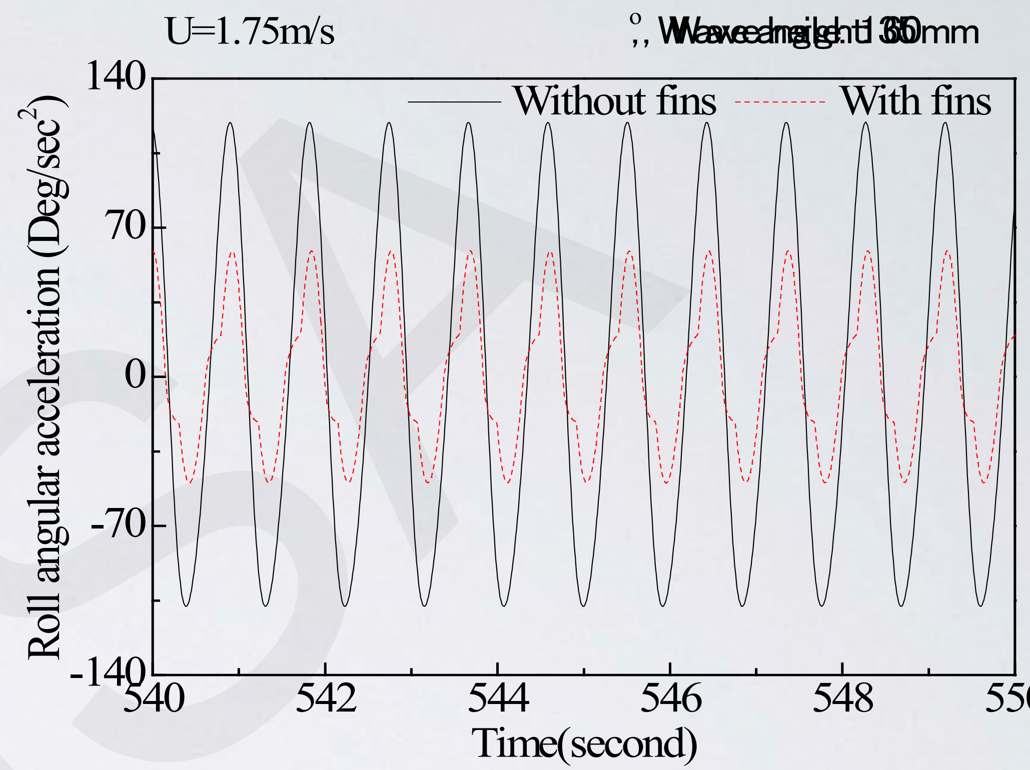
(*a*) (*b*)

Figure 2 (*a*) Heave and (*b*) pitch RAOs of the 8000 TEU container model: Froude number F_n=0.21, head sea with wave slope of 0.02.

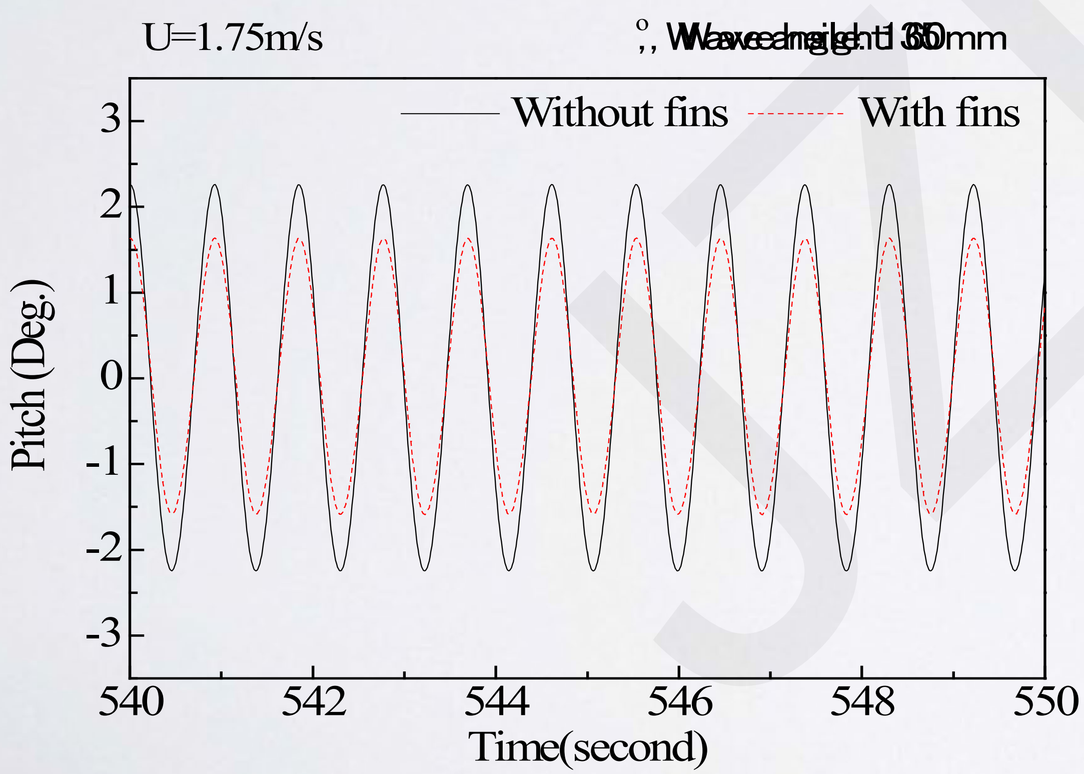
Numerical simulations of joint pitch-roll stabilization



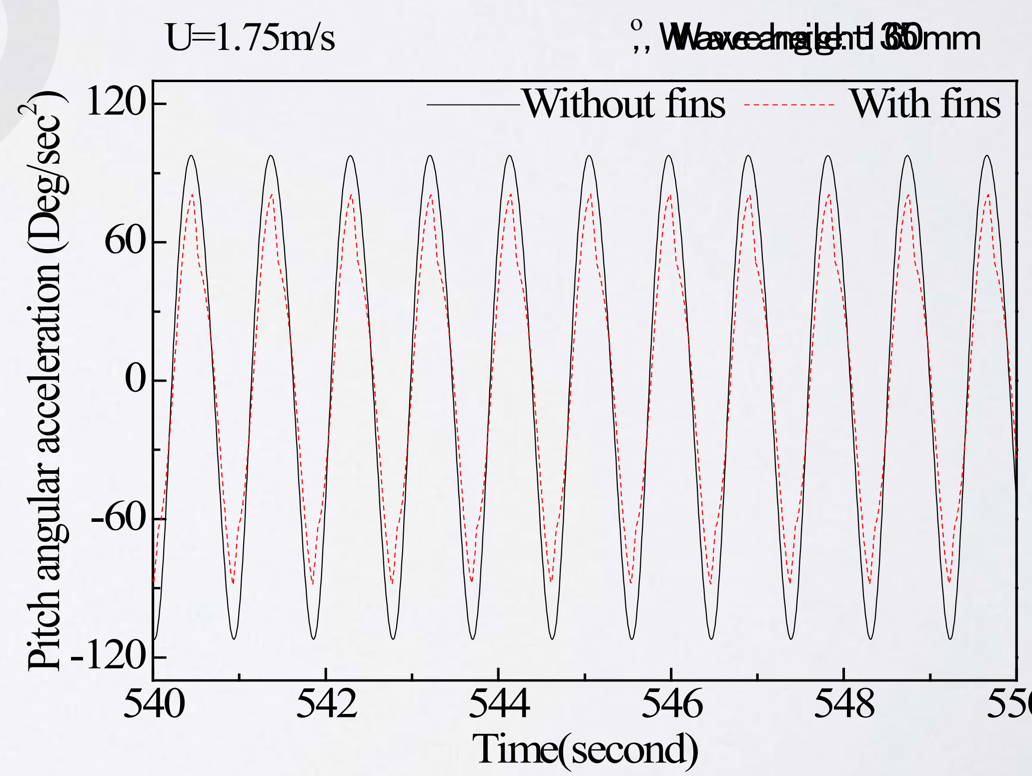
(*a*) Roll angle.



(*b*) Roll angular acceleration.



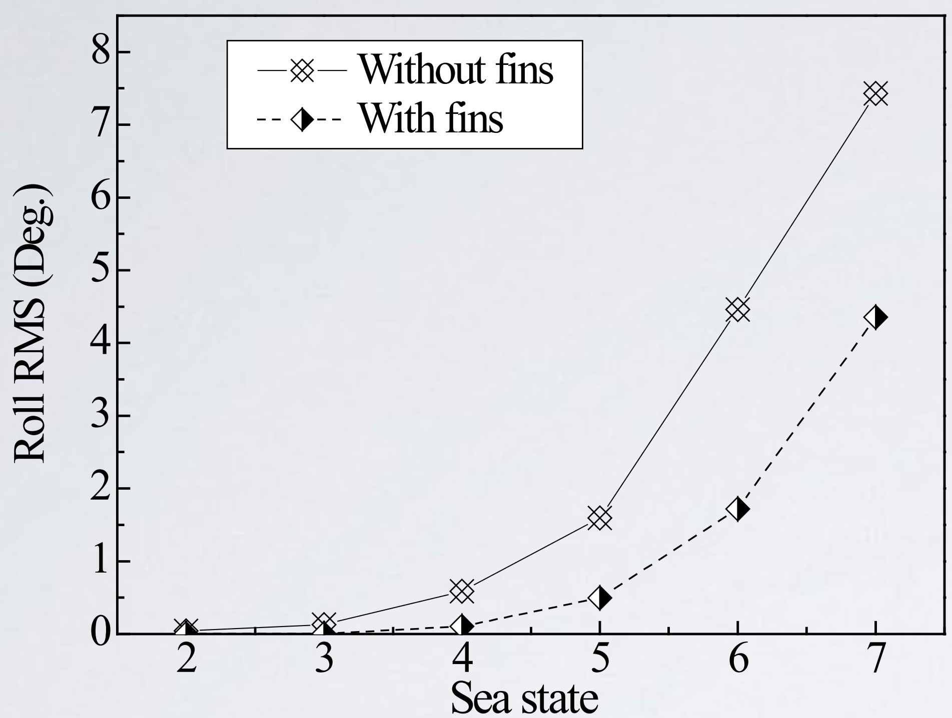
(*c*) Pitch.



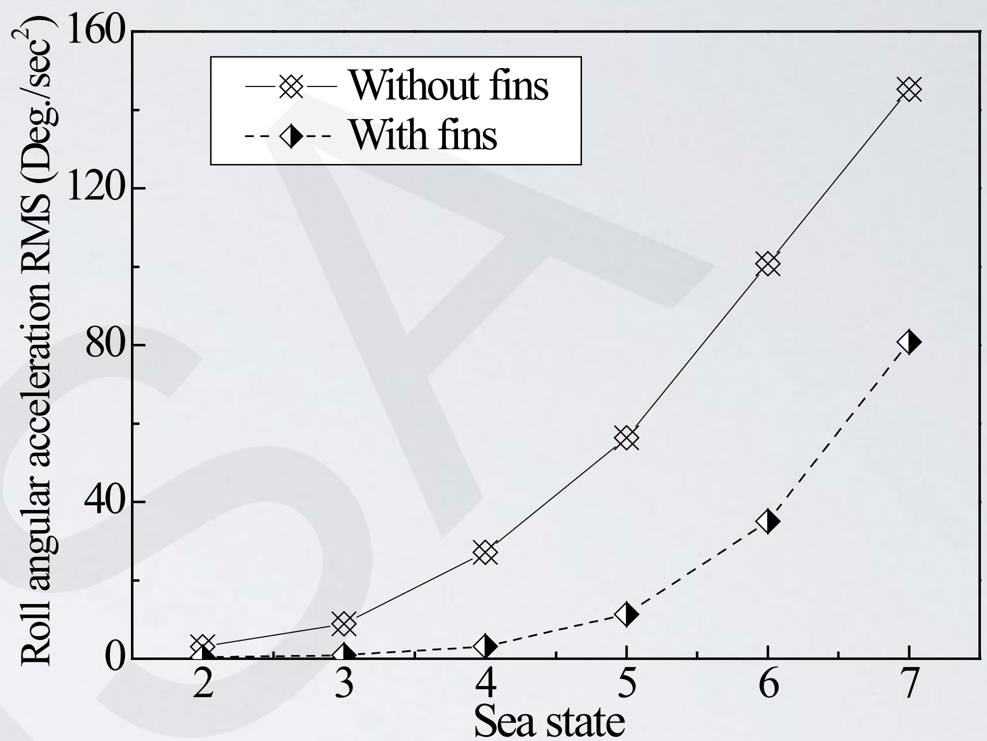
(*d*) Pitch angular acceleration.

Figure 3. Numerical results of the joint pitch-roll stabilization in regular wave (λ/Lpp=1.0).

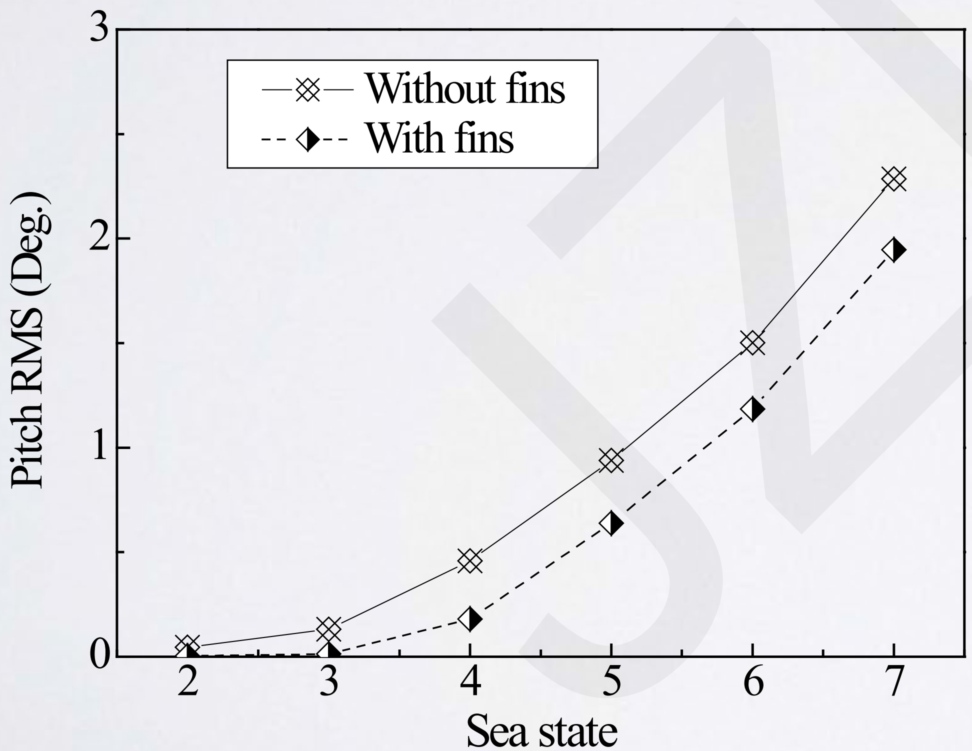
Numerical simulations of joint pitch-roll stabilization



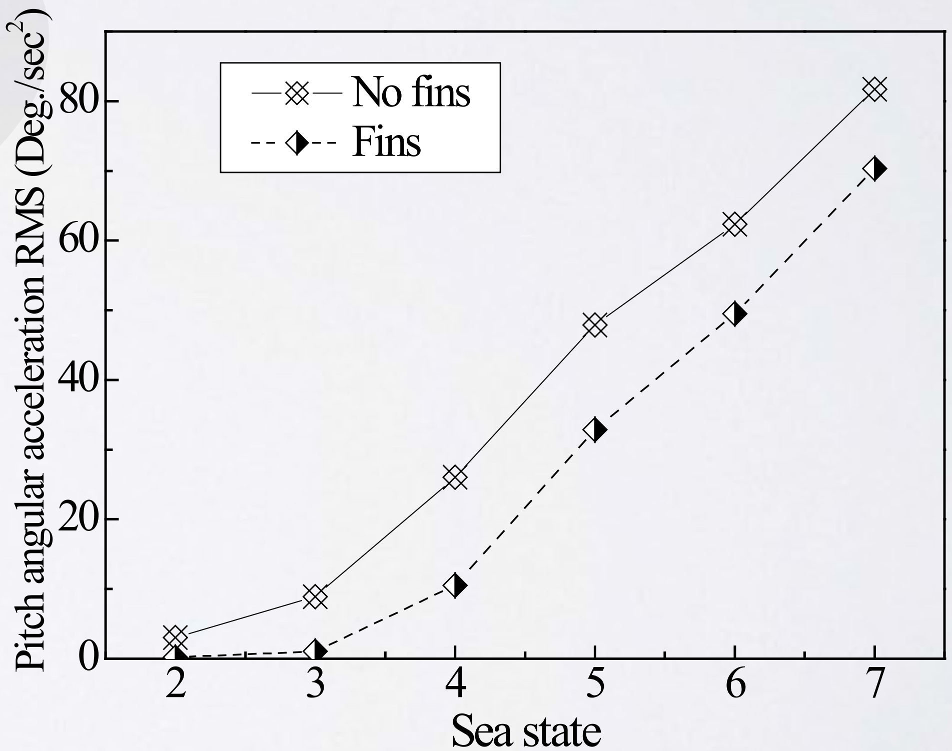
(*a*) Roll angle.



(*b*) Roll angular acceleration.



(*c*) Pitch.



(*d*) Pitch angular acceleration.

Figure 4. Comparison of motion RMSs with and without active fins at various sea states.

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Conclusions

Validation of the weakly nonlinear 2.5D sea-keeping analysis approach.

- Results of both blunt and fine hull shape ships consistently show that the weakly nonlinear 2.5D approach consumes less computational time compared to 3D method with equivalent accuracy, and requires equivalent computational cost with obvious higher accuracy than the conventional 2D method.

The SMHFP controller is applied to control four stabilizing fins simultaneously.

- Numerical simulations of joint pitch-roll stabilization under various regular wave conditions and sea states 2~7 were carried out.
- Pitch and roll motion were efficiently controlled.
- The average reduction ratios of roll motion are more than 70% while those of pitch motion are more than 30% under regular wave conditions.
- In the typical condition of sea state 5, the average reduction ratios of roll motion are more than 69% while those of pitch motion are more than 31%.