Route Optimization of Wind-Assisted Ship in Non-uniform Wind and Wave Conditions

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1. INTRODUCTION

Utilizing wind power is necessary to achieve net zero CO2 emission declared by International Maritime Organization. Rigid wind sails and rotor sails are the most common sailing systems available in the market.

There are several sailing systems proposed by researchers. Rigid wind sail[1)], rotor sail[2)] and kites are the most common sailing systems developed so far. Force generation capacity of rigid wind sails depends on lift and drag coefficients, projected surface area of sail, and apparent wind speed. In order to increase the performance of sailing system, angle of attack, ship speed and ship route should be controlled.

In the present study, we have optimized the route of the ship and operating conditions of rigid hard sail. The angle of attack was determined at each time step to maximize thrust and route was defined by control points.

2. METHOD

Wind is an environmental force acting on ships and captains usually avoid strong winds due to the safety of ships. However, wind-assisted ships need strong winds to reduce energy consumption at utmost level. For this purpose, the route of wind-assisted ships differs from conventional ships depending on the weather forecast. In addition to optimizing route, it is necessary to control sailing system to maximize the thrust to reduce the propeller power consumption.

Target ship considered in this study is KVLCC2[3)]. Airfoil of the rigid wind sail was chosen as NACA0012. The relation between angle of attack and lift/drag coefficients were obtained based on previous studies[4)]. The angle of attack needs to be updated through route to achieve maximum propulsive thrust. In order to determine the angle of attack, a wind sail controller was designed to maximize the propulsive forces.

The route of the ship was defined by control points as shown in Fig. 1. Ship speed was given as 6 m/s. Control points were considered as design variables of the optimization problem. Objective function was defined as total power consumption of propeller.

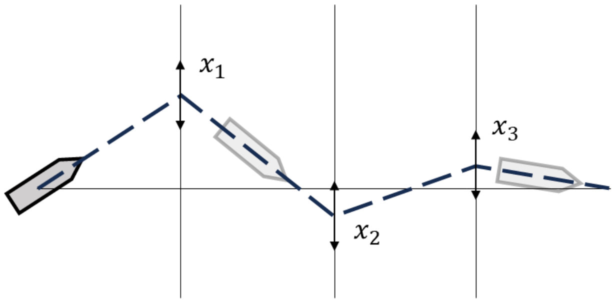

Fig. 1　Design variables to define the route.

The overall system workflow was given Fig 2. Route data of each optimization step was sent to PID controller. Position and heading errors were calculated and propeller speed (n) and rudder angle (δ) were determined. Then, angle of attack is determined based on wind and ship conditions.

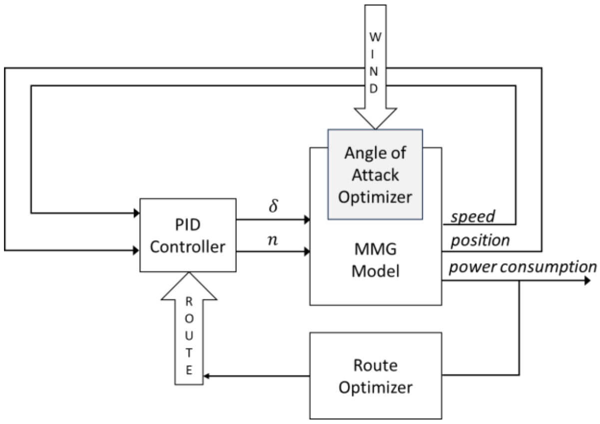

Fig. 2　Workflow of the optimization of wind assisted ship operation.

3. RESULTS AND DISCUSSIONS

In the present study, wind and wave conditions were defined based on Beaufort scale, in other words, wind and wave data were correlated. Wind direction and wave direction are also assumed to be the same. In the problem given in Fig. 3, the direction and magnitude of environmental forces were defined in corners and interpolated through the inside of the domain. The upper boundary of the design domain whose length is 100 km has an environment at Beaufort scale of 9 and that of bottom boundary is Beaufort scale of 3. True wind/wave angle was considered as 0, 45, 90, 135, and 180 degrees.

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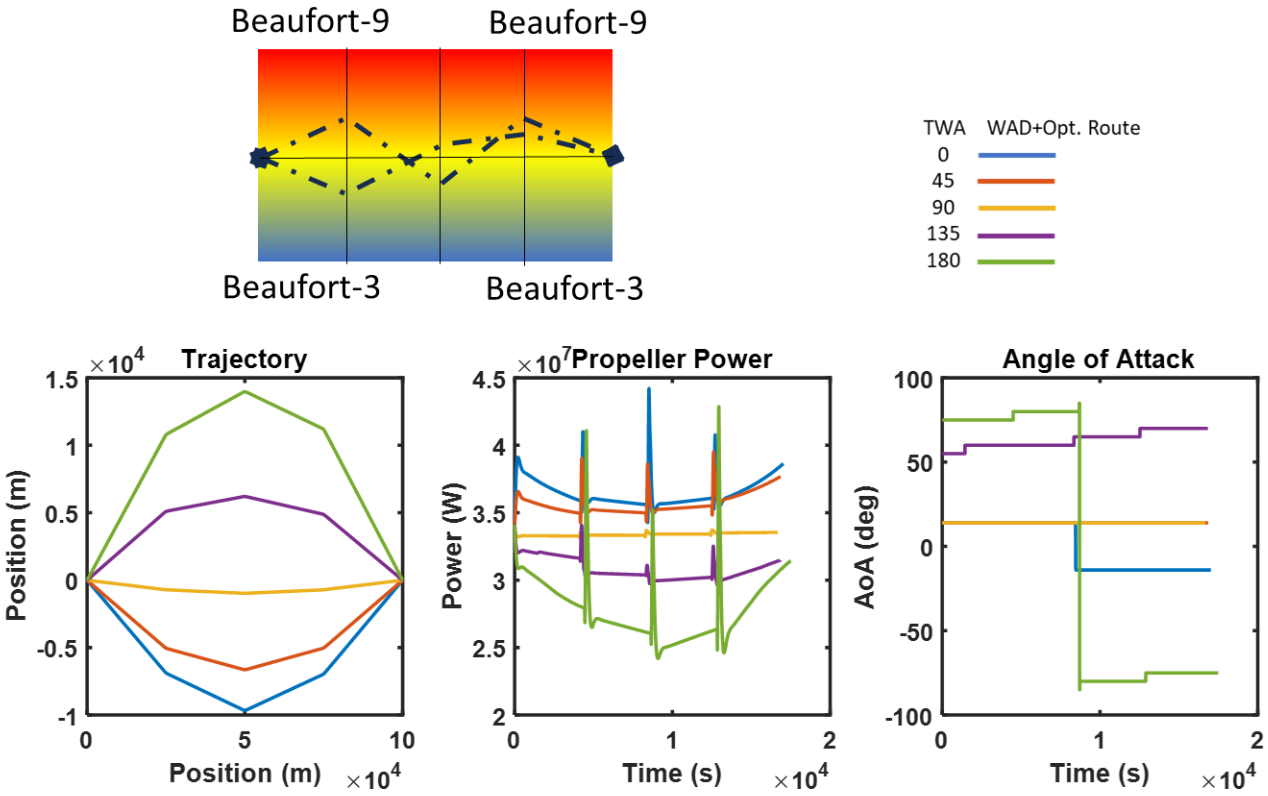

Fig. 3 Overall workflow of the ship model.

According to Fig. 3, when backwind conditions exist, the ship tends to go to the upper boundary where strong winds exist. On the other hand, when wind comes from the front side, the ship goes to a lower boundary and exposes to low wind speed environment to reduce the wind resistance. Power consumption was found to be lower in the case of TWA=180 deg, because ship exposes larger wind speed and generates larger thrust forces.

The angle of attack also changes during the course of ship depending on the wind direction. We found that angle of attack was around ±15 degrees when TWA is equal to 0, 45, and 90 degrees. When TWA is 135 degrees, angle of attack was changed to the range of 55-75 degrees. Further, angle of attack was changed between ±80-85 degrees when TWA is 180.

We have investigated the performance of wind-assisted ships by optimizing the operational conditions of the ship and sailing system. It was found that route optimization led the ship to operate where lift and drag coefficients were maximized. When TWA is equal to 0, 45 or 90 degrees, angle of attack was around 12 degree which provides the maximum lift coefficient. The drag coefficient was maximum around 80-85 degrees which was the case where TWA is equal to 180. However, a transition phase between maximum lift and maximum drag was found when TWA is equal to 135 degrees.

5. CONCLUSIONS

In the present study, we have investigated the operational conditions of ship and wind sail system. It was revealed that it is quite important to find optimal working conditions for wind-assisted ship to obtain the maximum propeller power reduction.

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REFERENCES

1) K. Ouchi et al.: “Wind Challenger” the Next Generation Hybrid Sailing Vessel. Third International Symposium on Marine Propulsors, 2013.

2) F. Tillig and J. Ringsberg: Design, operation and analysis of wind-assisted cargo ships. Ocean Engineering, Vol211(1), pp. 1-23, 2020

3) H. Yasukawa and Y. Yoshimura: Introduction of MMG standard method for ship maneuvering predictions. Journal of Marine Science and Technology, Vol20, pp. 37–52, 2015.

4) R.E. Sheldahl and P. C. Klimas, Aerodynamic characteristics of seven symmetrical airfoil sections through 180-degree angle of attack for use in aerodynamic analysis of vertical axis wind turbines, U.S. Department of Energy, Office of Scientific and Technical Information, Technical Report, 1981. https://doi.org/10.2172/6548367