"Wind Challenger" the Next Generation Hybrid Sailing Vessel

Kazuyuki Ouchi[1], Kiyoshi Uzawa[1], Akihiro Kanai[2] and Masanobu Katori[3]

[1]The University of Tokyo, Tokyo Japan,
[2]ACT Inc., Hayama Kanagawa-ken Japan, [3]North Sails Japan Inc., Yokohama Japan

ABSTRACT

The Wind Challenger Project which was started by The University of Tokyo and Japanese major shipping companies is researching to utilize the maximum ocean wind power for the main propulsion of a large cargo vessel. The concept of "Motor Assisted Wind Powered Vessel" is proposed as the next generation sailing vessel named UT WIND CHALLENGER. The vessel is equipped with extraordinary large rigid sails on the upper deck as a main propulsor which is made by advanced light material such as CFRP composite. The rigid sail has the crescent wing section and also has vertically telescopic reefing and self rotating mechanism to meet the wind velocity and direction. The nine pieces of rigid sails (total sail area 9,000m2) are expected to generate forward thrust enough to drive 180,000DWT Bulk Carrier at the speed of 14knots, in case of wind velocity of 12m/s from a beam. The aerodynamic interaction of the nine wing sail system is carried out with the full scale CFD simulation. Furthermore, a study on the fuel oil saving effect in the real sea such as the route between Yokohama and Seattle was carried out and about 30% of propulsion energy is acquired from the wind power in average.

Keywords

Sailing Ship, Wing Sail, Energy Saving, Composite, Voyage Simulation

1 INTRODUCTION

In order to move toward the era of a low-carbon society, it is necessary to drastically reduce CO2 emissions from large ocean-going merchant vessels that are invariably burning fossil oil. However, it may be impossible to reduce fossil fuel use by more than 50% in the case of same speed and deadweight. Thus, a change of energy source for ship propulsion is absolutely needed for the next generation of merchant vessels. The candidates would be driven by wind, nuclear energy, fuel cells, battery, bio-fuel, etc. From the viewpoint of sustainability and energy costs, it is clear that ocean wind power which is free and stronger than the wind in land is the best solution to drive slow-speed vehicle such as a very large merchant vessel. In order to make a sailing merchant ship revive in future, the ship should have a concept of not only energy saving eco-ship but also fitting for the punctuality which is very important requirement for the current global logistics. Following the demise of traditional sailing merchant ships in the beginning of 20th century, very few modern sailing ships have come to replace them. The *Shin-Aitoku Maru* shown in Fig. 1, which has cambered hard sails made of metallic cambered board, was developed by JAMDA Japan in the 1970s as one of the great challenges for a new concept sailing vessel (Endo et al 1982). Several Japanese ships were fitted with this type sails, however, it was faded out together with decreasing of fuel oil price.

Fig. 2 shows *Beluga Sky Sail*, which is a kind of kite developed in Germany last year. Both technologies seem to be categorized as a "Sail Assisted Motor Ship", and the reduction of fuel oil consumption is about 10% in mean value during a year.

Fig.1 Shin-Aitoku Maru

Fig.2 Beluga Sky Sail

2 MOTOR ASSISTED WIND POWERED VESSEL

A concept of "Motor Assisted Wind Powered Ship" which is mainly powered by wind energy and oil burning engine as auxiliary is needed for the future low carbon society. The wind powered merchant vessel of fuel oil reduction by 50% is proposed as WIND CHALLENGER in this paper. For example, the principal particulars of the 180,000DW vessel so called Cape-Size Bulker are shown in Table 1. The image picture of full sail at the sea is shown in Fig.3 and reefing the sail in port is shown in Fig.4. The vessel has nine CFRP rigid wing sails which can be rotated 360° to meet the wind direction and reefed telescopically by a mechanical devices inside of the sail (Ouchi and Uzawa 2009).

Table 1 Particulars of Wind Challenger

Length	: 300m
Breadth	: 50m
Depth	: 25m
draft	: 16m
Dead Weight	: 180,000t
Sail Area	: 9,000m2
Aux. Engine	: 12,000KW
Service Speed	: 14kt
Complement	: 25 Persons
Kind of Vessel	: Cape-Size Bulker

Fig.3 Wind Challenger in the Sea

Fig.4 Wind Challenger in the Port

The forward thrust T (kgf) generated by the wing sail shown in Fig.5 is expressed as follows,

$$T = 0.5 \cdot \rho a \cdot Va^2 \cdot A \cdot Cx \qquad (1)$$

Where,

Density of the air: ρa ($kg \cdot s/m^4$)

Apparent Wind Speed: Va (m/s) , shown in Fig.5

Area of wing sail: A (m^2)

Thrust coefficient: Cx (Variable Parameter according to the Apparent Wind Angle θ shown in Fig.5. The figure is shown in the polar diagram of Shin-Aitoku Maru's rigid cambered sail on Fig.6, for example.)

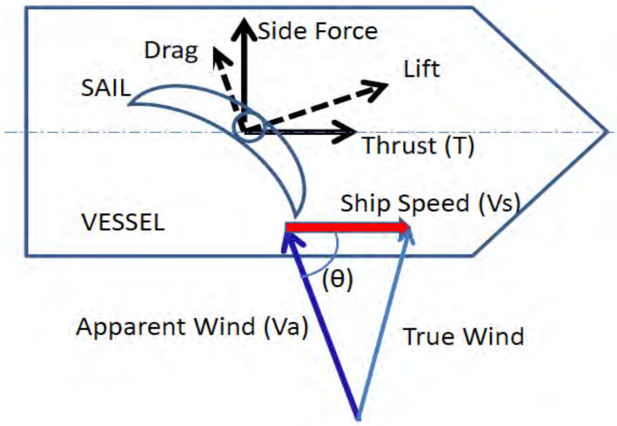

Fig.5 Apparent Wind and Thrust

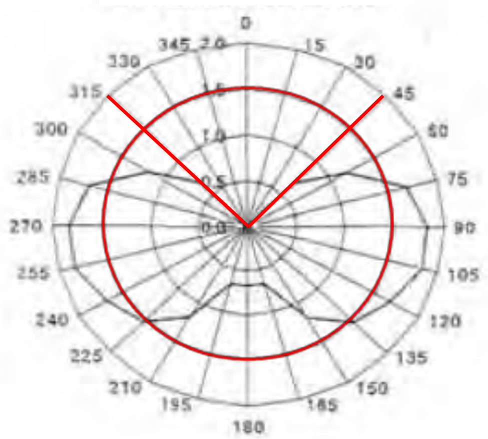

Fig.6 Polar Diagram (Cx/θ Curve)

In the case of the Cape-Size Bulker shown in Table1, following parameters are used for the performance estimation ;

$\rho a = 0.125$ ($kg \cdot s/m^4$)

A = 1,000 (m^2) x 9 pieces

Cx = 1.5 (in case of apparent wind angle θ about 315°— 0°—45°shown in Fig.6)

According to the equation (1), Table 2 shows the thrust of an each sail (T) and total thrust of nine sails (Tt) acting on the vessel. Table2 also shows the Effective Horsepower (EHP) and Brake Horsepower (BHP), the vessel's speed (Vs) and Froude Number (Fn) corresponding to the total thrust, considering general propulsion performances of the typical Cape-Size Bulker in the current shipbuilding market.

Table 2 Wind, Thrust, Power and Speed

Va m/s	T ton･f	Tt ton･f	EHP KW	BHP KW	Fn $V_s/\sqrt{Lg}$	Vs kt
4.0	2	14	334	463	0.047	4.9
6.0	3	30	1,126	1,564	0.070	7.4
8.0	6	54	2,669	3,707	0.093	9.8
10.0	9	84	5,213	7,241	0.116	12.3
12.0	14	122	9,008	12,512	0.140	14.7
14.0	18	165	14,305	19,868	0.163	17.2
16.0	24	216	21,353	29,657	0.186	19.6

From this estimation, it is known that 12m/s side wind can drive the vessel at the speed of almost 14knot without engine.

Schedule keeping is now very important mission of the recent sea transportation, therefore, assistance of engine power for the propulsion is necessary considering the variability of the wind, and furthermore, the vessel have to use the engine instead of the sails in the port and narrow channel to keep proper maneuvability for the safety. So that the auxiliary engine and propeller is fitted and the way of sharing the necessary thrust is studied. Fig.7 shows the relation between wind speed and engine power.

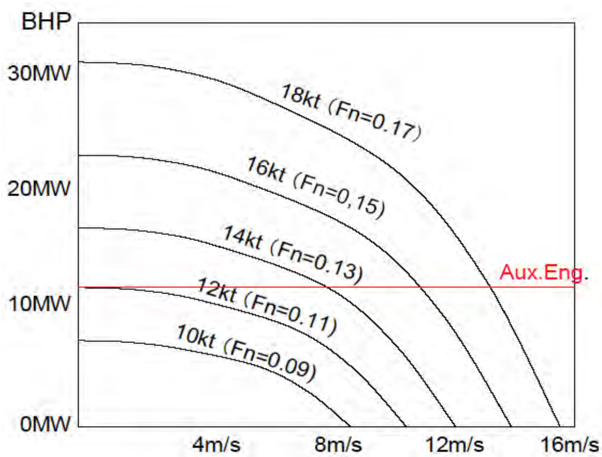

Fig.7 Relation between Wind Speed and Engine Power

3 PERFORMANCE PREDICTION BY CFD

CFD simulations were carried out to predict the aerodynamic forces generated by the 9 wing sails at the full scale, considering the interaction of sails and ship's hull [3]. The grid used is an unstructured hexahedral grid with about 8 million cells and the RANS solver Fine/Marine was used. The 3D model for the CFD simulations is shown in Fig.8.

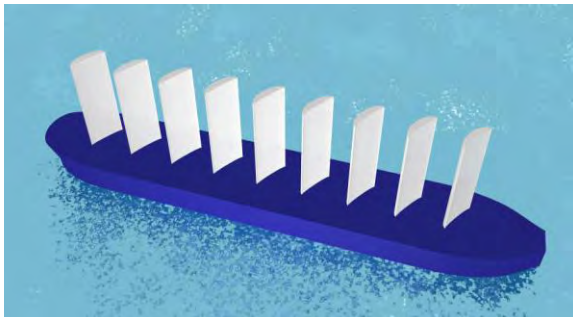

Fig.8 3D Model for the CFD Simulations

The apparent wind angle (AWA) was varied from 30 to 165. The flow visualization around the 9 wing sails at AWA=30, 120 and 150 are shown in Fig.9. The wing sail angles were adjusted to maximize the total thrust force and as shown in the figure the interaction between wing sails is the key point for that.

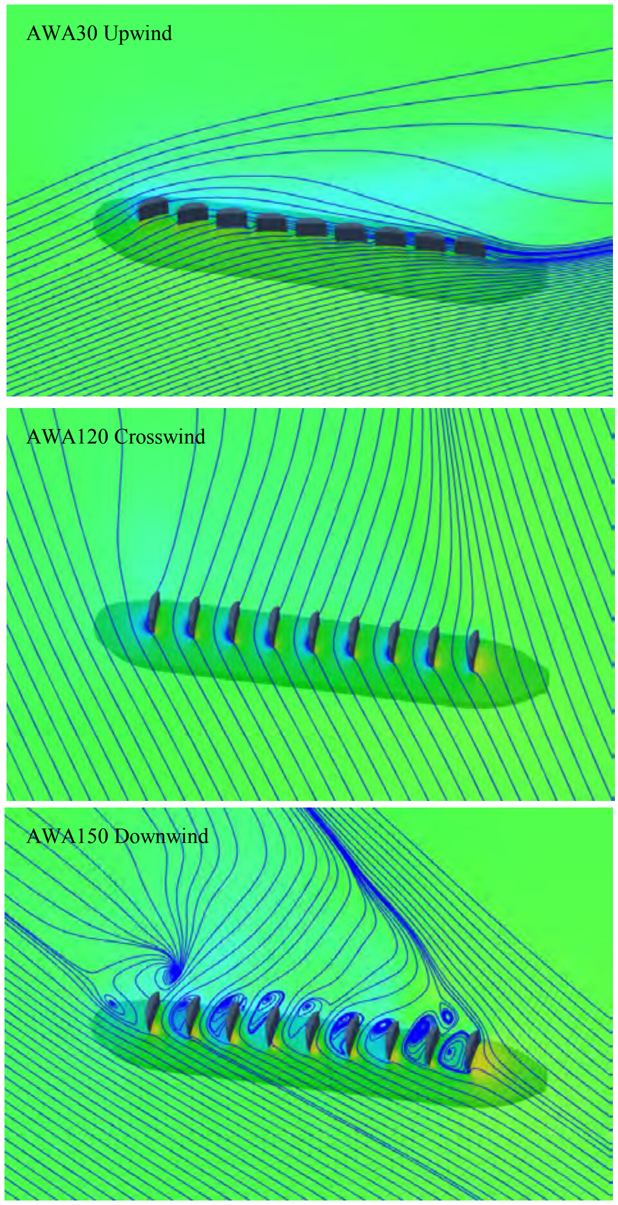

Fig.9 CFD Simulation around the Sails

Fig.10 shows the thrust force distribution on every wing sail at AWA=30, 120 and 150. Due to the strong interaction at AWA=30 the thrust force distribution shows the peak at the forefront wing sail and decrease towards the aftermost one.

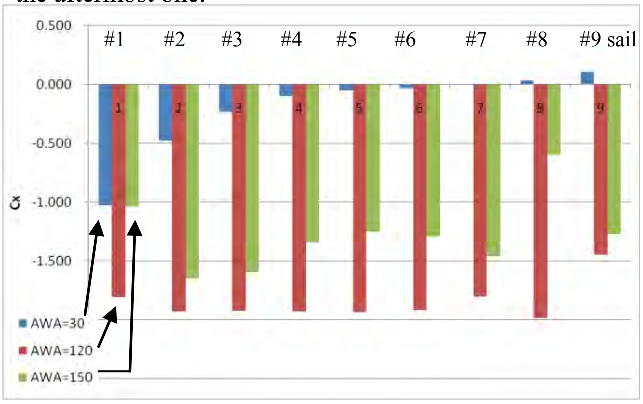

Fig.10 Thrust Force Distribution on Every Wing Sail at AWA=30, 120 and 165

From these CFD simulations the thrust force, side force and moment around a vertical axis on each wing sail are determined and used as a wing sail model for the ship performance prediction. For a sailing yacht the VPP is the performance prediction program and the EPP (Energy Prediction Program) was developed in this study to predict the performance of the motor assisted sailing vessel. The force models for the hull and rudder were also included.

The true wind speed, true wind direction and boat speed are given as the initial condition and the leeway angle, rudder angle and BHP to assist the sail thrust force to achieve the target boat speed are acquired in the EPP. For the Cape-Size bulker in this study the CPP propeller is adopted and the propeller pitch angle is solved.

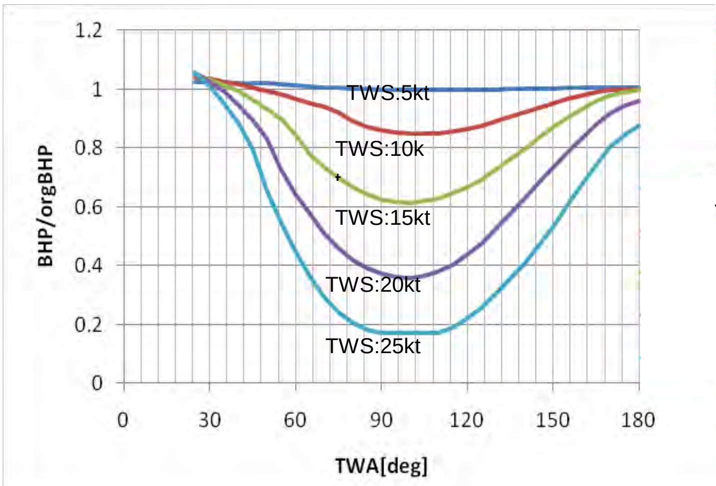

Fig.11 BHP Ratio of the Wind Powered Bulker against Original Cape at Boat Speed=14kt

The output BHP divided by the BHP of an original Cape-Size bulker with no wing sails is shown in Fig.11. It is indicated that more than 80% of the energy consumption can be reduced by the wing sail power in the condition of AWA80～120°and wind velocity 25knots (Kanai et al 2011).

4 RIGID WING SAIL OF GFRP COMPOSIT

The huge telescopically retractable rigid sail is considered to be made of GFRP+Aluminum honey-comb sandwich panel, which is very light and strong. The size is 50m height, 20m breadth, and 4m thickness. And it also rotate to meet the wind direction together with the steel spars inside. Fig.12 shows the 3-D perspective drawing of the sail at the condition of fully developed.

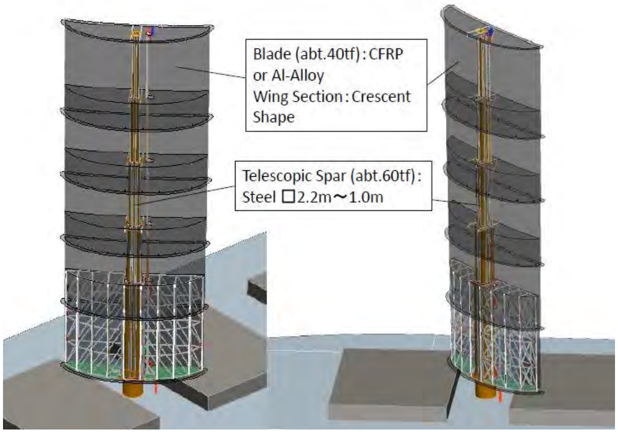

Fig.12 3-D perspective drawing of the sail

Fig.13 shows the preliminary calculation for a deflection and stress of the rigid wing sail by FEM method. It is confirmed that the rigid sail of this construction concept can be withstand against the drag of 700KN （$0.7KN/m^2$） in case of 30m/s wind velocity from the normal direction. The total weight of spars and sail are estimated approximately 100 tons

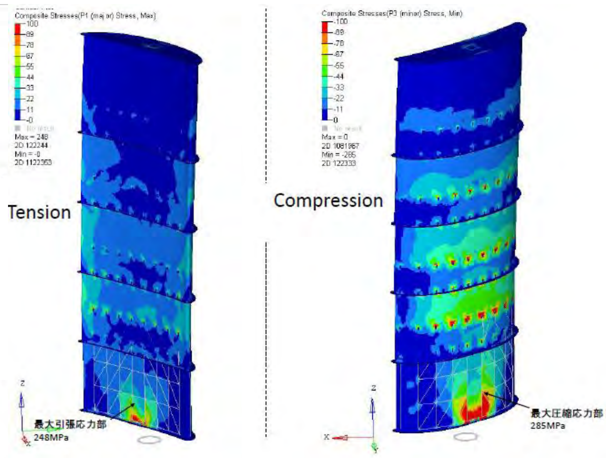

Fig.13 Deflection and Stress of the Sail

5 VOYAGE SIMULATION

In order to estimate the reduction of fuel oil consumption of the Wind Challenger in the real sea, the simulation of wind power acquisition using actual data of wind velocity and direction (6 hours average in 2004) is carried out in case of the voyage of Yokohama/Seattle (Ouchi et al 2011).

Three voyage routes were investigated;

①Great Circle (Ship Speed Constant)

②Great Circle (Engine Power Constant)

③Optimum Route (Engine Power Constant)

Fig.14 shows the above 3 routes. Here, the Optimum Route is off Great Circle and choosing the route of stronger and cross wind area.

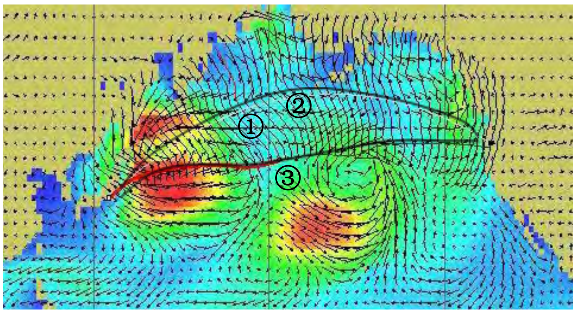

Fig.14 Great Circle and Optimum Route

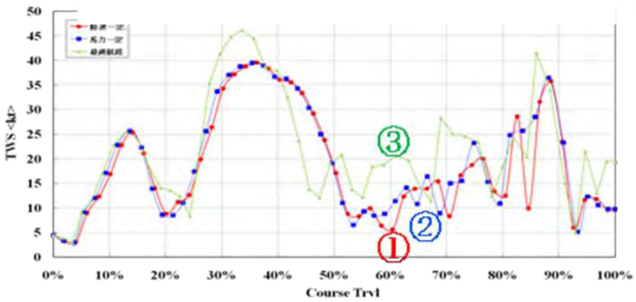

Fig.15 Time History of True Wind Speed.

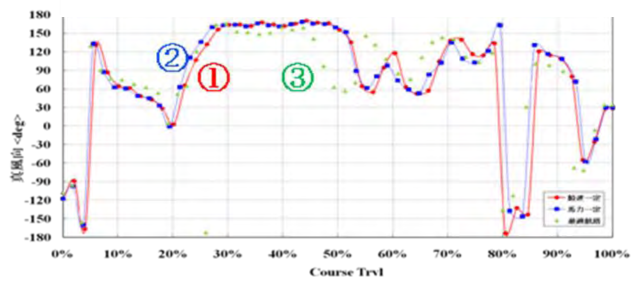

Fig.16 Time History of True Wind Direction.

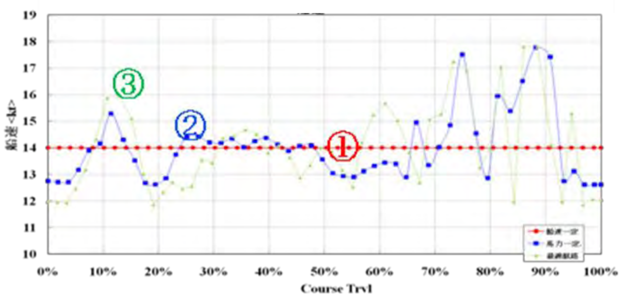

Fig.17 Time History of Ship Speed.

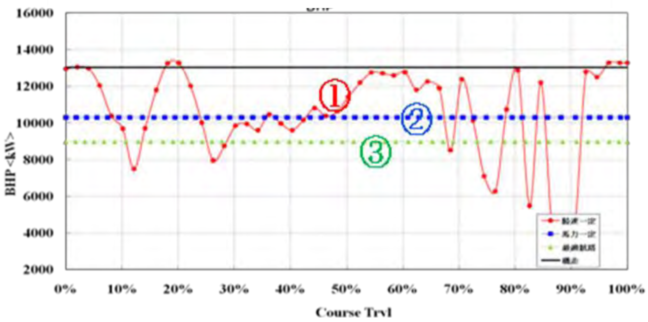

Fig.18 Time History of Main Engine Power.

Fig.15, Fig.16, Fig.17 and Fig.18 show the time histories of actual wind velocity, wind direction, ship speed and main engine power relatively during the whole voyage. From these studies, in case of choosing Great Circle route, the wind power acquisition ratio (fuel oil saving ratio) is about 22% in both case of ship speed constant① and main engine power constant ② . Furthermore, in case of choosing Optimum Route ③, the fuel oil saving ratio increases to 30% in spite of rather longer distance route than Great Circle. So that, in order to maximize the fuel consumption ratio, it is very important to research into the strategy of the optimum route choice and utilizing weather forecasting.

6 CONCLUSIONS

The Wind Challenger Project which is aiming to utilize the maximum ocean wind power proposes new concept hybrid propulsion system, Motor Assisted Wind Powered Ship. So far, the followings are concluding remarks.

- The extra-ordinal large rigid wing sail which is rotating and retracting telescopically is developed and confirmed its feasibility.
- From the study of an example ship 180,000 DWT Cape-Size Bulker who has 9 sails (total 9,000m2 sail area), the energy save ratio is estimated more than 80% in the condition of cross wind 12m/s, at the ship speed 14kt.
- The energy saving simulation in the actual voyage (Yokohama/Seattle) is carried out and it is found that the fuel oil saving by 20～30% is very possible.
- Land based one year endurance testing of the 1/2 scale prototype rigid wing sail will be scheduled in the summer of 2013, to confirm the functions and obtain various data, which is very important to equip for the real ship.

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