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Sailing performance of the ship by wind turbine generator

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Abstract

A prediction concerning to the sailing performance of the ship with wing stroke mechanism was undertaken solving the fundamental equation consists of aerodynamic and hydrodynamic drag of the system and the thrust of the propeller which is driven by the wind power generation. .

It could be said that the ability of sailing toward the wind which is necessary to the practical feasibility of the concept as to the merchant services can be improved under the strong wind condition.

1. Introduction

Harmonizing to the world-wide spreading of wind energy utilization, the potential of wind-energy conversation in ocean is re-considered and under investigation now.

The author has long been made a research for this area, standing on an small experience as a sail-boat designer and an engineer for modern wind turbine generator.

In this paper, at first a comparison between various types of sailing apparatus was briefly made, and next the potential of the sailing-ability by a new sailing apparatus called wing-stroke mechanism was investigated by simulation.

Although this kind of theme should be treated by experiments like a testing of the model-ship, the paper only shows the result of theoretical approaches, because the author has not yet a chance to build such a device that might be my biggest concern in the future.

2. Comparison between various sailing apparatus.

Fig.1 shows the difference of the three types of sailing apparatus namely conventional-rig, kite-rig and the wing-stroke mechanism which was invented by the author.

2-1. Conventional-rig

This type of rig has been most popular but only for the area of sports for a long time.

Under the conditions of severe competition, although much effort has been done to improve the performance of the rig as well as for the hull, the results were not sufficient to widen these technology for commercial area because of the strict limit to keep the symmetry of the basic configuration which limits the lift to drag ratio of the rig and the hull considerably low.

In addition, higher requirement of operational skill consists of mental and physical aspects of human ability prevents the system from industrialization.

So, this type may remain for eternal in a heritage of tradition and education.

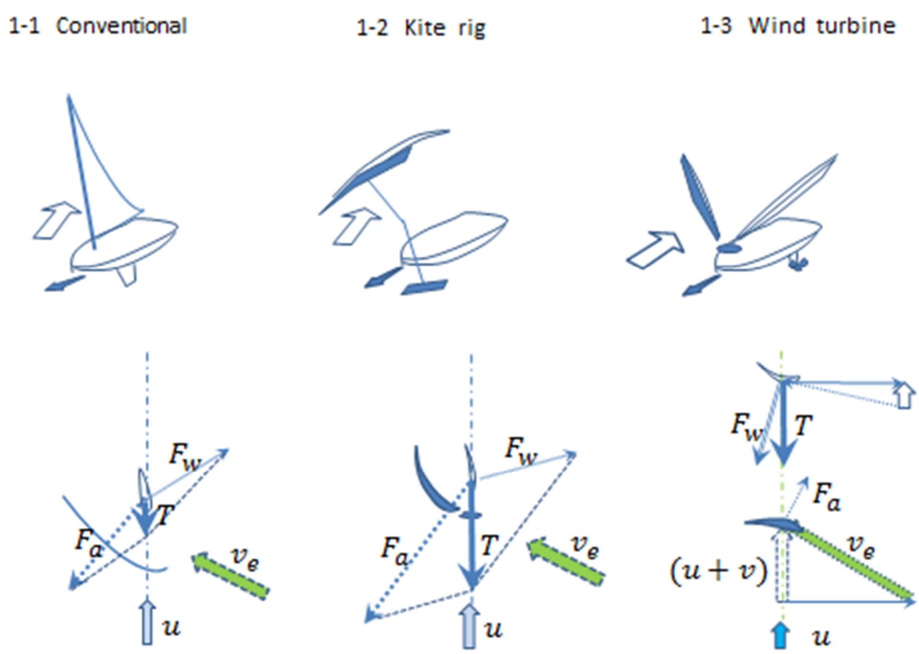

Fig.1 Comparison between various sailing apparatus.

2-2. Kite-rig

Although this kind of sailing apparatus is not yet commercialized, there was a little trial in early '70 in Japan by the author as is shown in Fig.2 which is alike to the recent technology of modern wind-surfing.

Fig.2 A prototype of the kite-rig

The advantages of this system are

a) Substantially there is no healing moment.
b) Kite could be designed as a high-lifting type with comparatively high aspect ratio.
c) Hydro-foil is also can be designed with asymmetrical wing-section that prevent the side slip of the hull completely.
d) As a result, the device can produce a higher level of thrust.
e) It allows fully automatic control not only for the rig but also for the total ship.

In Nov. 1991 a conceptual proposal shown in Fig.3 utilizing this kind of rig was awarded at the competition by NIKKEI.

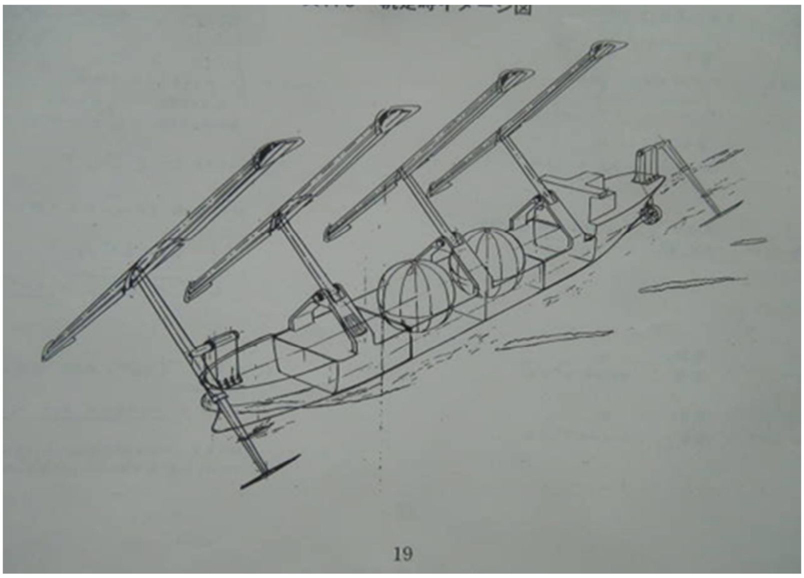

Fig.3 Ocean-going Kite-rig to capture hydrogen

It could be supposed that, by the operation of hundreds of these ships, around one-thirds of the electricity consumed in Japan could be supplied economically.

2-3. Wind-turbine

With this method, as is discussed later, the potential to set the course according to wind direction can be much improved.

2-4. A feasibility study of comparison in a conceptual stage.

The author tried to make a comparison between these different technical method for sailing as is shown in Fig.4.

As a result, if the freedom of sailing freely in the ocean is allowed, the kite-rig has a tremendous potential as an energy system with high level of the contribution.

Nevertheless, in this paper I would like to focus on the wind-turbine type because there could be seen more technological points to be discussed.

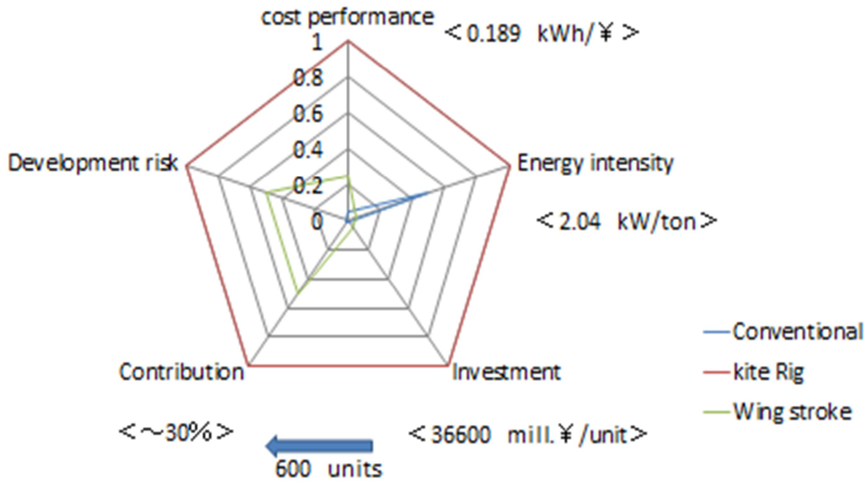

Fig.4 Comparison between various concepts for sailing

3. Modeling the sailing ship by wind turbine.

3.1 Comparison between various wind turbines

Fig..5 shows the difference of the basic characteristics between various type of wind turbine.

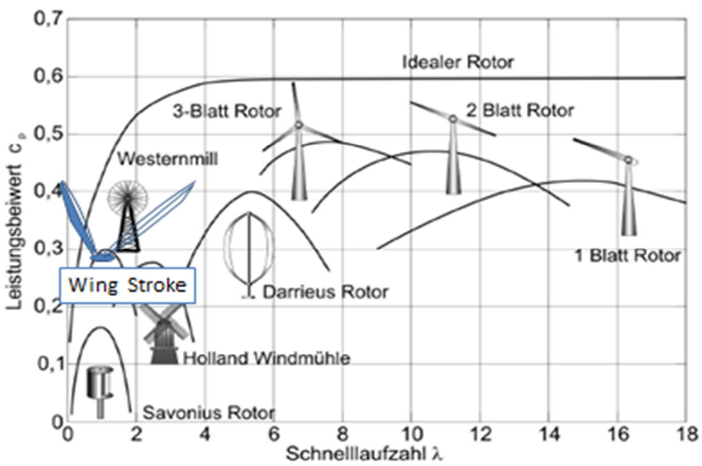

Fig.5 An over-view of various type wind turbine

When we propel the ship by the electricity produced by wind turbine generators, followings conditions are required for example,

・substantially high power coefficient.

・lower aerodynamic thrust compared to the power.

・lower weight to power ratio.

・safety in strong wind condition.

In this paper three types of wind turbine generator, namely Horizontal axis wind turbine, Darrieus type wind turbine and Wind stroke type wind turbine are chosen for the comparison.

3.2 Estimation of the aerodynamic thrust.

It is recognized that in order to evaluate the performance of sailing particularly against the wind, the amount of thrust to power ratio is most important.

Fig.6 shows the principle relationship between an ideal aerodynamic thrust T_0 and an additional thrust T_A.

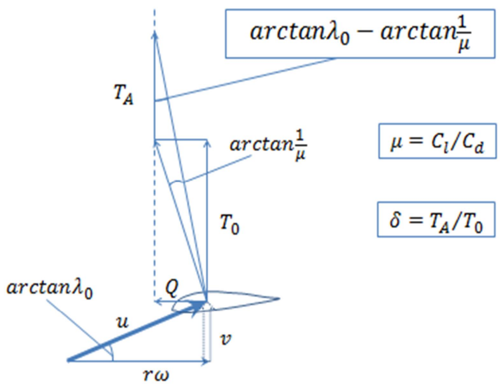

Fig.6 T_A/T_0 affected by C_l/C_d of the wing section

If we define C_l/C_d of the wing as μ and T_A/T_0 as δ, the relationship between aerodynamic torque Q and aerodynamic thrust T can be calculated like,

$$Q/T = \tan\left(\arctan\ \lambda_0 - \arctan\ \frac{1}{\mu}\right) \tag{1}$$

hence $$Q/T = \frac{Q}{T_0 + T_A} \tag{2}$$

and $$T_0/Q = \lambda_0 \tag{3}$$

as a result $$1 + \delta = \frac{\lambda_0}{\tan\left(\arctan\ \lambda_0 - \arctan\ \frac{1}{\mu}\right)} \tag{4}$$

In Fig.7 the variation of $1 + \delta$ corresponding to λ_0 and μ is shown.

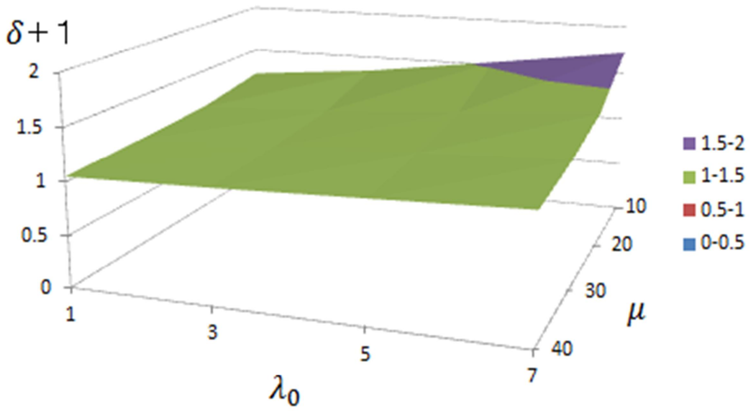

Fig.7 the variation of $1+\delta$ corresponding to λ_0 and μ

Finally, if we assume that the tip-speed ratio of turbine as 1, 5 and 7, and $\mu = 20$ we get the thrust coefficient and the C_T/C_p of each turbine as is shown in Table-1

	Wing stroke	Darrieus	HAWT
λ_0	1	5	7
ω	1	5	7
C_p	0.25	0.4	0.49
C_q	0.25	0.08	0.07
C_{T_0}	0.25	0.4	0.49
$\delta + 1$ at $\mu = 20$	1.105	1.262	1.36
C_T	0.276	0.505	0.667
C_T/C_p	1.104	1.263	1.359

Table-1 Basic characteristics of various wind turbine

3.3 Basic design of each turbine.

As a preparation of the simulation of total ship system, we may design specific wind turbines applying the basic characteristics under discussion.

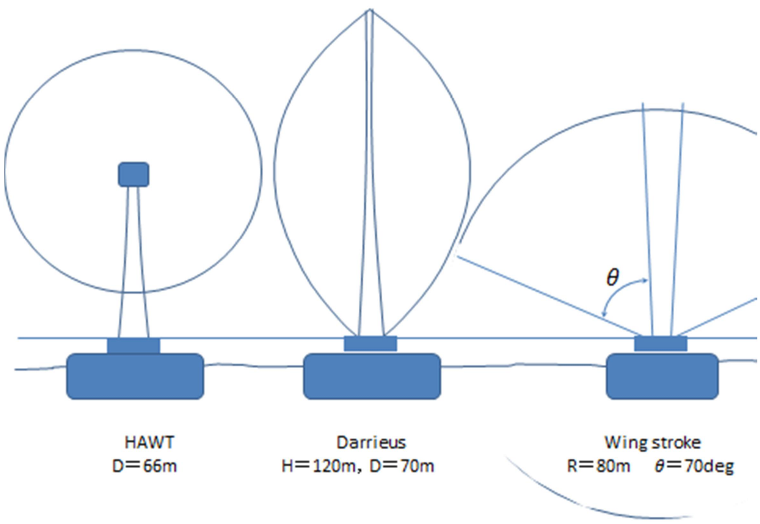

Fig.8 Comparison of the proportion between various wind turbine design

Fig.8 shows the difference of the proportion for the similar out-put level of 2MW, and in Table-2 representative specifications of each turbine are described.

	HAWT	Darrieus	Wing stroke	reference
Swept Area m^2	3418	5469	6700	
Height m	83	120	80	
Weight of turbine ton	330	235	140	
Height of Thrust Center m	70	70	55	
Height of turbine weight m	50	48	22	
C_T	*0.667	0.505	0.276	*0.5 by IEC 61400-2

Table-2 Specification of the various type 2MW class wind turbine.

3.4 Basic design of the ship.

After the study, basic dimensions of the ship with the displacement of 50 thousand ton were specified as is shown in Fig.9.

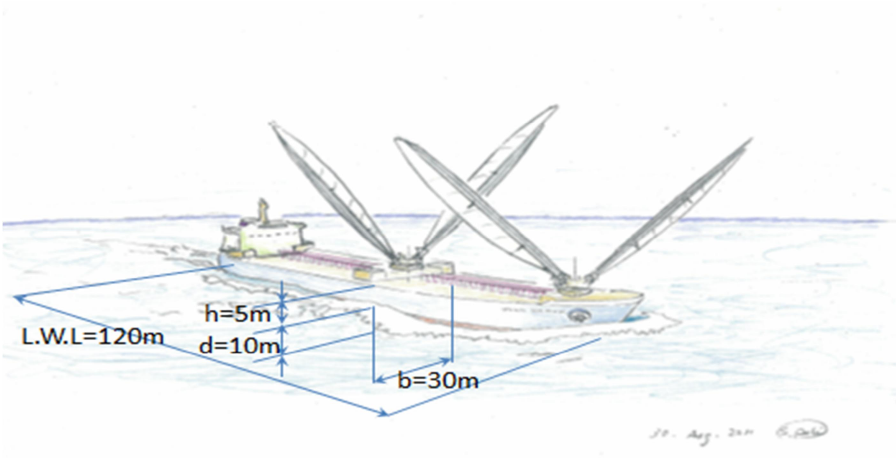

Fig.9 Basic dimensions of the ship

3.5 Estimation of the aerodynamic and hydrodynamic drag of the ship.

Hereinafter also corresponding studies were conducted and the aerodynamic drag and the hydrodynamic drag of the ship itself was estimated like,

a) Aerodynamic drag of the ship

$$D_a = 0.275\ {v_e}^2 \quad \text{(mega-newton)} \tag{5}$$

b) Hydrodynamic drag of the ship

$$D_w = 0.96u^2 \quad \text{(mega-newton)} \tag{6}$$

3.6 Estimation of the thrust by propeller.

Assuming that the proportion of the induced flow around the propeller is constant, a formula of the estimation according to the ship speed u is derived like.

$$T_w = (0.2 - 0.0133u)\ P_0 \quad \text{(mega-newton)} \tag{7}$$

3.7 Final equation of the motion.

Assuming that the aerodynamic forces are influenced by the inflow angle φ, equations of the motion for various type of the wind turbine are conducted like,

$$T_w - (T_a + D_a)\cos\varphi \ - D_w = 20000\frac{d^2u}{dt^2} \tag{8}$$

As to the aerodynamic thrust of the turbine T_a, corresponding coefficient is to be applied like,

$$T_a = 1.402 v_e^2 \qquad \text{(mega-newton)} \qquad (9) \quad (HAWT)$$

$$T_a = 1.6747 v_e^2 \qquad \text{(mega-newton)} \qquad (10) \quad (Darrieus)$$

$$T_a = 1.146 v_e^2 \qquad \text{(mega-newton)} \qquad (11) \quad (Wing\ Stroke)$$

4. Simulation result of the sailing.

4.1 Sailing against the wind by various type of wind turbine.

In order to make a direct comparison between various type of wind turbine, a simulation based on equation (8) was conducted in the condition of sailing against wind, that means the inflow angle φ is to be zero, as is shown in Fig. 10.

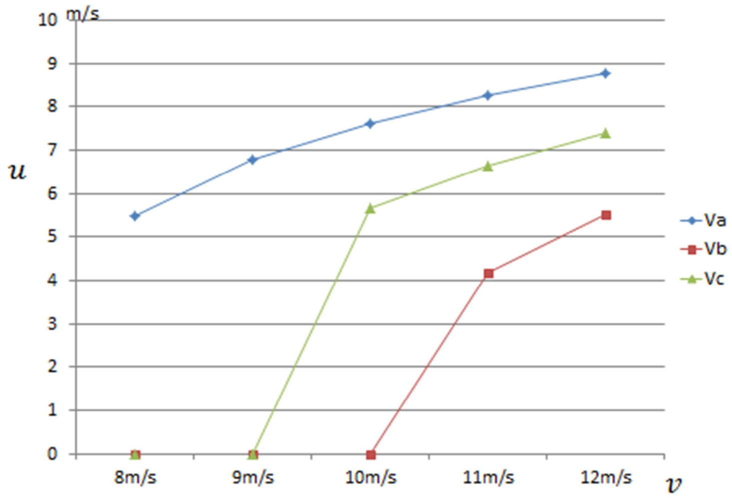

Fig.10 Comparison between various types of wind turbine as the propulsion system.

The result shows the influence of the difference of the aerodynamic characteristics of each turbine like the ratio of the coefficient of thrust and the coefficient of power C_T/C_P, namely the wing stroke system has the best performance of acceleration while the HAWT shows the worst.

4.2 Potential of sailing by the wing-stroke mechanism.

Fig. 11 shows a prototype of the wing-stroke system under development.

Fig.11 Prototype of the wing-stroke system.

Although the main object of this concept is to eliminate the acoustic noise by lowering the tip-speed ratio through all the operating conditions, as is shown on Table-1, it could be recognized that the fundamental aerodynamic characteristics are noticeable including the unique points like the proportion between the thrust and the torque is considerably low.

Simulations under various conditions as to wind speed and wind direction was conducted to make a radar chart shown in Fig.11.

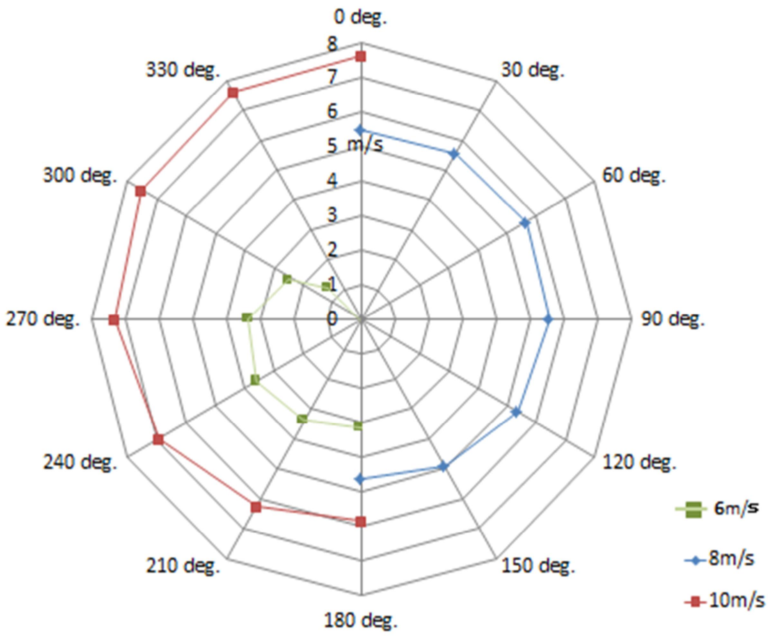

Fig. 11 Sailing radar chart of the Wing Stroke Ship

The result clearly shows the difference of the performance under lower, middle and higher wind speed in all the direction as to the relationship between the running course of the ship and the wind direction.

Under the wind speed of 6 m/s, sailing against the wind is almost impossible, but increasing the wind speed enables the performance of sailing toward the wind as well as the speed itself.

5. Conclusions.

- Modern wind turbine can be used as a power source of the ship which is driven by the electricity.
- Sailing performance is affected by the efficiency and the aerodynamic characteristic of the wind turbine, particularly the proportion of the thrust and the power coefficient of the turbine.
- Application of the wing-stroke mechanism that flaps wings makes an improvement for the sailing performance of such a kind of ship.

Nomenclature and Abbreviation

b :	Breadth of the Hull
C_d :	Drag coefficient of the aero-foil section
C_l :	Lift coefficient of the aero-foil section
C_q :	Torque coefficient of the wind turbine
C_P :	Power coefficient of the wind turbine
C_T :	Thrust coefficient of the wind turbine
C_{T_0} :	Thrust coefficient of the wind turbine in case of 2D ideal flow
d:	Draft of the ship
D:	Diameter of the HAWT(Horizontal axis wind turbine)
D_a:	Aero-dynamic drag of the ship
D_w:	Hydro-dynamic drag of the ship
F_a:	Aero-dynamic force in case of sailing
F_w:	Hydro-dynamic force in case of sailing
h:	Difference between depth and draft of the hull
H:	Height of the Darrieus type wind turbine
L.W.L:	Length water line
P_0 :	Power consumed by propeller
Q :	Aero-dynamic torque of the wind turbine
r :	Radius of the rotation
T :	Aero-dynamic thrust of the wind turbine
T_a :	Aero-dynamic thrust of the wind turbine in the system
T_0 :	Aero-dynamic thrust of the wind turbine in case of 2D ideal flow
T_A :	Additional thrust caused by additional drag

T_w : Hydro-dynamic thrust of the propeller

u: Running speed of the ship

$\boldsymbol{u}$: Resultant velocity of the air-flow

Va: Final speed of the wing-stroke system

Vb: Final speed of the HAWT system

Vc: Final speed of the Darrieus system

v : Wind speed

v_e : Effective wind speed

δ : T_A/T_0

θ: Stroke angle

λ: Tip-speed ratio

λ_0: Tip-speed ratio in case of 2D ideal flow

μ : C_l/C_d

φ: Inflow angle

ω : Angular velocity of the rotation

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