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Relation between P-D value of Autopilot and Transfer Distance under Wind Pressure

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Abstract : *When performing steering by an autopilot (automatic steering gear), a sensitivity adjustment is mainly determined by P value and D value. These values differ in the optimal combination by model of ship and external forces. This research was carried out simulation case studies and examined movement of Pure Car Carrier, which easily received ship by wind pressure influence in low speed. We investigated the relation of horizontal migration(transfer) of ship's body and P-D value. Based on it, four parameters of P-D at approaching berth could be suggested. Hence there were suggestions of parameters; Distance to maximum lee point, Time to maximum lee point, Time to return to original course and Time to 300th second. The correlation of these parameters and P-D value were also considered. As a result, we think that this index, like formulated P-D, leads to an easy and safe navigation by utilizing these indices.*

Key words : *Autopilot, P-D value, Wind pressure, Effective handling of rudder, Safety navigation*

1. Introduction

In ports or coastal area, a ship must carry out sensitive navigation for approaching berth at low speed. Rudder effectiveness at this rate is poor and a mariner must, simultaneously, perform appropriate maneuverabil- ity due to external forces like wind and current. Therefore, low speed navigation under wind pressure is quite difficult compared to that in an ocean(Hara, 2006).

Nevertheless, only a few studies have been made, so far, on sensitive navigation and guidance under wind force(Lee, 2007). The present condition is that a captain or pilot navigates with his experience and skill. The purpose of this paper is to demonstrate simulation, and to guide navigation of safety under the influence of wind pressure.

The data obtained are used as a index for safety navigation. The target ship simulated against wind influence was a PCC which easily received. For one case, the simulation time is set to 300 seconds.

In this simulation, an autopilot concerns in ship's control and the sensitive adjustment by P and D values of it. We investigated the combination of P and D values(or gains) and the relation to the horizontal migration distance (Transfer, m) of a ship's hull. Based on that, we create an index using P-D value in the low speed navigation.

This paper intends to find the combination which performs the most sensitive navigation within the permissible transfer(m). Throughout it, we consider the relation between P-D value of autopilot and transfer distance under wind pressure. It is used for the safety index of navigation in sensitive handling performance. As a result, we hope that this index, like formulated P-D, leads to an easy and safe navigation by utilizing these indices.

2. Autopilot and P-D control

2.1 Autopilot

If a ship swerves from the course while sailing within a defined route, a ship operator will learn of this deviation from a gyrocompass and he or she will take the rudder to return to the original course. When maintaining the heading via autopilot instead of an operator, the sensitive adjustment is mainly determined by P(proportional) and D(derivative) value.

These values differ in an optimal combination by type of ship, character and external forces. P value is one which determines P operation (Return rudder) of auto pilot. P operation is taking the rudder angle in proportion to the deviation.

For example, rudder angle is also great if the deviation is great. Conversely, if a deviation is minor, a small angle of rudder will be required. Therefore, P operation will use a big rudder angle for a small deviation if the P value is large. In general, it can be expressed with $P \times \beta$ (P value

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×Deviation).

D value (D) determines D operation (Reliance rudder) of autopilot. D operation is taking a rudder angle in proportion to angular velocity $d\theta$.

When angular velocity is quick, it means a large rudder angle taken. D operation also reacts to slight angular velocity. This can be expressed by $D\times\dfrac{d\theta}{dt}$.

2.2 Parameter to index

Fig. 1 show us four steps for formulating the index of P-D. The parameters by P and D value above, is explained in the following:

① Distance to maximum lee point : maximum distance off the original course in which a ship is pushed to the leeward side by wind pressure. Permissible Transfer (m) refers to this distance.

② Time to maximum lee point : Time until a ship reaches maximum lee point.

③ Time to return to the original course : Time until a ship moves forward on wind and intersects the original course again.

④ Distance to the 300th second : Distance until a ship reaches the 300th second from the original course.

The most important among these are ① and ②. That is because the navigation case in simulation is a kind of approaching berth, which is important for making a short-time motion of ship's hull.

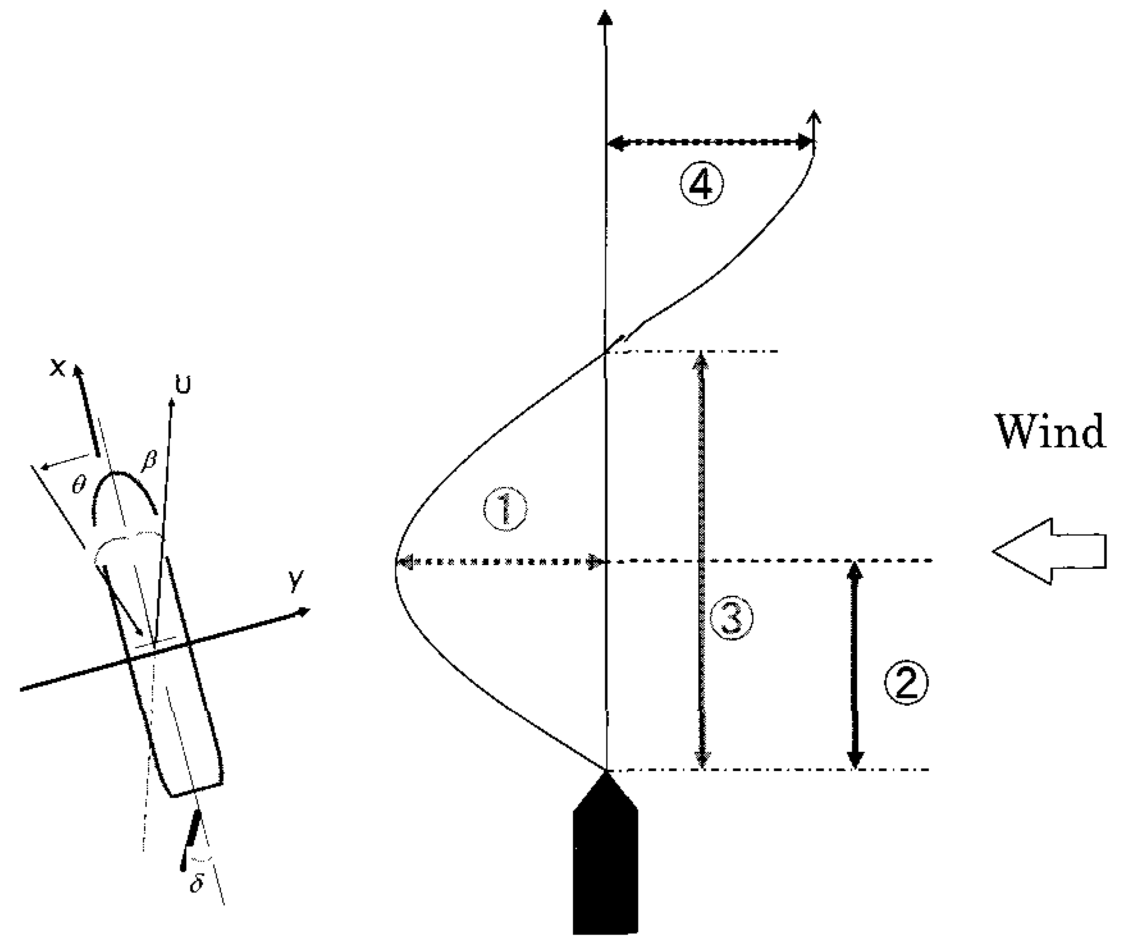

Fig. 1 Coordinate system and definition of parameters

3. Framework of simulation

3.1 Condition for simulation

① Table of P-D

The combination is composed of each P-D combination of 0~3000 shown as table 1.

② External force

The simulation navigates under wind (steady during 300 seconds) 30 kts from 90 starboard side in original course and no other external force(current, wave etc).

③ Model ship

Table 2 is the particular which shows on model ship.

The speed in simulation is set up on 6 knots.

Table 1 P-D value and relations with each parameter (below : P value right : D value)

a. Distance to maximum lee point

	0	5	10	15	20	30	40	50	60	100	150	200	250	300	350	400	450	500	550	600	750	1000	2000	3000
0	8.1	9.0	10.1	10.5	11.5	12.8	13.6	14.3	14.8	16.3	17.2	17.9	18.1	18.5	18.7	18.7	19.0	19.0	19.2	19.3	19.5	19.7	20.1	20.2
300	9.3	10.8	11.4	12.4	12.9	13.8	14.5	15.1	15.6	16.9	17.7	18.2	18.5	18.7	18.9	19.1	19.2	19.3	19.4	19.5	19.7	19.8	20.2	20.3
600	11.3	12.3	13.0	13.5	13.9	14.6	15.2	15.7	16.1	17.3	18.1	18.5	18.8	19.0	19.1	19.3	19.4	19.5	19.5	19.6	19.8	19.9	20.2	20.4
900	12.8	13.5	14.0	14.3	14.4	15.3	15.8	16.2	16.6	17.5	18.5	18.6	19.1	19.2	19.4	19.4	19.6	19.6	19.7	19.7	19.8	20.0	20.3	20.4
1200	14.0	14.4	14.7	15.0	15.3	15.8	16.3	16.6	17.0	18.0	18.8	19.1	19.3	19.4	19.5	19.6	19.7	19.7	19.8	19.8	19.9	20.1	20.3	20.4
1500	14.8	15.0	15.4	15.6	15.9	16.1	16.6	16.8	17.3	18.2	19.0	19.3	19.5	19.6	19.7	19.7	19.7	19.9	19.9	19.9	20.0	20.2	20.3	20.5
1800	15.4	15.6	15.9	16.1	16.3	16.6	17.0	17.2	17.5	18.3	19.1	19.5	19.7	19.7	19.8	19.9	19.9	19.9	20.0	20.0	20.1	20.3	20.4	20.5
2100	15.9	16.1	16.3	16.5	16.5	16.9	17.2	17.5	17.7	18.5	19.1	19.7	19.8	19.9	19.9	19.9	20.0	20.0	20.1	20.1	20.2	20.3	20.4	20.5
2400	16.2	16.5	16.6	16.7	16.9	17.2	17.5	17.7	17.9	18.5	19.2	19.7	19.8	20.0	20.0	20.1	20.1	20.1	20.2	20.2	20.2	20.3	20.5	20.6
2700	16.7	16.8	16.9	17.1	17.2	17.4	17.7	17.9	18.0	18.6	19.2	19.7	19.9	20.1	20.1	20.2	20.2	20.2	20.2	20.2	20.3	20.4	20.5	20.6
3000	17.0	17.1	17.2	17.2	17.4	17.5	17.8	18.0	18.2	18.6	19.2	19.6	19.9	20.1	20.1	20.2	20.2	20.3	20.3	20.3	20.4	20.4	20.5	20.6

b. Time to maximum lee point

	0	5	10	15	20	30	40	50	60	100	150	200	250	300	350	400	450	500	550	600	750	1000	2000	3000
0	78	82	93	102	105	109	115	120	123	130	133	136	136	138	138	138	139	139	139	139	140	140	141	141
300	85	97	105	108	111	116	121	124	127	133	135	136	137	138	138	139	139	139	139	140	140	141	141	141
600	100	108	111	114	117	121	124	127	129	133	136	137	138	138	139	139	139	140	140	140	140	141	141	142
900	107	114	117	119	122	124	127	129	131	135	136	138	138	139	139	139	140	140	140	141	141	141	142	142
1200	115	120	121	123	124	127	129	131	133	136	138	139	139	139	140	140	140	140	141	140	141	141	142	142
1500	121	123	124	125	127	129	131	132	134	136	138	139	139	140	140	141	141	140	141	141	141	141	142	142
1800	124	126	126	128	129	131	133	133	134	136	139	139	140	140	140	141	141	141	141	141	141	142	142	142
2100	127	128	129	130	131	133	133	134	135	137	138	139	141	140	141	141	141	141	141	141	142	142	142	142
2400	129	130	130	131	132	132	134	135	136	137	138	140	141	141	141	141	141	142	141	141	142	142	142	142
2700	130	130	131	132	132	133	135	135	135	137	139	140	141	141	142	142	141	141	142	142	142	142	142	142
3000	132	132	133	132	133	134	135	136	136	137	139	140	141	141	141	141	141	142	141	141	142	142	142	143

c. Time to return to original course

	0	5	10	15	20	30	40	50	60	100	150	200	250	300	350	400	450	500	550	600	750	1000	2000	3000
0	123	154	164	185	193	202	211	218	224	234	242	245	248	250	252	253	254	255	256	256	258	259	260	261
300	148	180	191	199	205	214	220	225	229	239	245	249	251	252	253	254	256	256	256	257	258	259	261	261
600	178	197	206	210	214	221	226	230	234	243	248	251	253	254	255	256	257	257	257	258	259	260	261	261
900	201	209	215	218	221	227	231	234	237	245	251	255	254	255	256	257	258	258	258	259	259	260	261	262
1200	214	218	221	222	227	231	235	237	241	247	252	254	256	256	257	258	259	259	259	259	260	261	262	262
1500	215	224	227	229	231	234	237	240	242	248	254	255	257	258	258	259	259	259	260	260	260	261	262	263
1800	227	229	231	233	234	237	240	242	244	249	254	257	258	259	259	259	260	260	260	260	261	262	263	263
2100	230	233	234	236	237	239	241	243	245	249	254	257	259	259	260	260	260	260	261	261	261	262	262	263
2400	234	236	237	238	240	241	243	245	246	251	255	258	260	260	260	260	261	261	262	262	262	264	263	263
2700	236	238	239	240	241	243	244	246	247	251	255	258	260	260	261	261	262	262	262	262	262	264	263	263
3000	239	240	241	242	242	244	245	247	248	251	255	257	260	260	261	262	262	262	262	262	262	263	263	263

d. Distance to 300th second

	0	5	10	15	20	30	40	50	60	100	150	200	250	300	350	400	450	500	550	600	750	1000	2000	3000
0	###	52.0	42.2	37.6	34.5	32.0	28.3	26.4	24.8	21.1	19.0	17.7	16.9	16.2	15.8	15.4	15.1	14.8	14.6	14.3	14.1	13.5	12.5	12.4
300	69.3	39.7	35.3	32.6	30.7	27.9	25.9	24.3	23.0	19.8	17.9	16.8	16.1	15.7	15.2	14.9	14.6	14.5	14.4	14.1	13.7	13.3	12.5	12.3
600	41.8	33.3	30.8	29.1	27.7	25.8	24.0	22.7	21.7	18.8	17.0	16.2	15.5	15.0	14.9	14.5	14.3	14.1	14.1	13.8	13.5	13.1	12.4	12.2
900	31.5	29.3	27.8	26.9	25.6	23.9	22.6	21.5	20.6	18.0	16.2	15.4	15.0	14.5	14.3	14.1	13.9	13.8	13.7	13.5	13.3	12.9	12.3	12.1
1200	28.0	26.6	25.3	24.7	23.9	22.6	21.5	20.6	19.8	17.4	15.6	14.9	14.5	14.2	14.0	13.8	13.7	13.5	13.5	13.3	13.1	12.8	12.2	12.0
1500	25.6	24.1	23.9	23.2	22.6	21.5	20.6	19.8	19.1	17.0	15.2	14.4	14.1	13.8	13.7	13.6	13.4	13.2	13.2	13.1	12.9	12.6	12.2	11.9
1800	22.9	23.3	22.6	22.1	21.6	20.6	19.9	19.2	18.6	16.7	15.0	14.0	13.6	13.5	13.4	13.2	13.1	13.1	13.1	12.8	12.7	12.4	12.1	11.9
2100	22.7	22.1	21.6	21.1	20.7	19.9	19.3	18.7	18.1	16.4	14.9	13.7	13.4	13.4	13.1	13.0	13.0	12.9	12.8	12.7	12.6	12.3	12.1	11.9
2400	21.6	21.2	20.7	20.4	20.0	19.3	18.8	18.2	17.8	16.2	14.9	13.7	13.6	13.0	12.9	12.8	12.8	12.7	12.6	12.6	12.5	12.3	12.0	11.8
2700	20.0	20.4	20.0	19.7	19.4	18.8	18.3	17.9	17.5	16.1	14.8	13.9	12.9	12.8	12.7	12.6	12.6	12.5	12.5	12.5	12.3	12.2	11.9	11.8
3000	20.1	19.6	19.4	19.1	18.9	18.4	17.9	17.5	17.2	16.0	14.8	13.9	13.1	12.6	12.5	12.5	12.4	12.4	12.4	12.3	11.9	12.0	11.9	11.8

3.2 Measure to make a index

First, we examine these four steps by simulation:

Table 2 Principle particulars of 4,500 Units PCC

Length overall, Loa(m)	175
Displacement, Δ (ton)	25,900
Breadth, B(m)	32
Draft, d(m)	8.8
Wind Projection Area of Lateral Side, Aw(m^2)	4,355

a. It creates a combination table of P and D values.
b. And we set up simulation by ② of 3.1 paragraph.
c. It performs a simulation according to the combination table of P-D by ③ of 3.1 paragraph.
d. From the data acquired in the simulation, It computes the distance to the maximum lee point, the time to maximum lee point, the time to return to the original course and the distance to be 300 seconds from the original course.

Second, we index this information and make a suggestion for combining them.
e. We index these four processes.
f. It determines the Permissible Transfer(m) to be 15m.
g. We search for a combination of P and D values within limits from the index distance to maximum lee point.
h. From the simulation data of these values, we make "Change of Rudder Angle" into a graph and determine the combination of the most highly sensitive P-D value.
i. In the case of determined P-D value, it verifies what kind of navigation is to be employed.

4. Numerical simulation

4.1 Estimation of parameters

From table 1 calculated, we could estimate further meaning and relation of each parameter.

① Distance to maximum lee point

Table 1 shows distances and times from the original course, which is recorded for each second of the simulation. In these mock-up conditions, the pressurized hull of a ship is uniformly advanced on the lee side after she starts the combination of all the P and D values. Then, the furthest distance from the original course is the distance to maximum lee point.

As a distance becomes shorter, the tendency is to have a small combination of P-D values. It will become longer if the combination of P-D becomes larger as well. The minimum is 8.1m of (P0, D0), and the maximum is 20.6m of (P3000, D3000) in Fig. 2.

It shows the relation among distance to maximum lee point, P and D value. If it changes in the place (0-250) where P value is small, most of the influence will be lost, even though it has a big influence on the change of distance and P value. Namely, the influence becomes smaller when it is combined with a big P value while the D value continues at a fixed influence on the change of distance.

The result is that P value has considerable influence on the distance to maximum lee point compared to D value. The same observation applies to the case that this relation becomes remarkable when the combination of P-D is small.

In other words, the distance to maximum lee point contracts as the combination of P and D values expand.

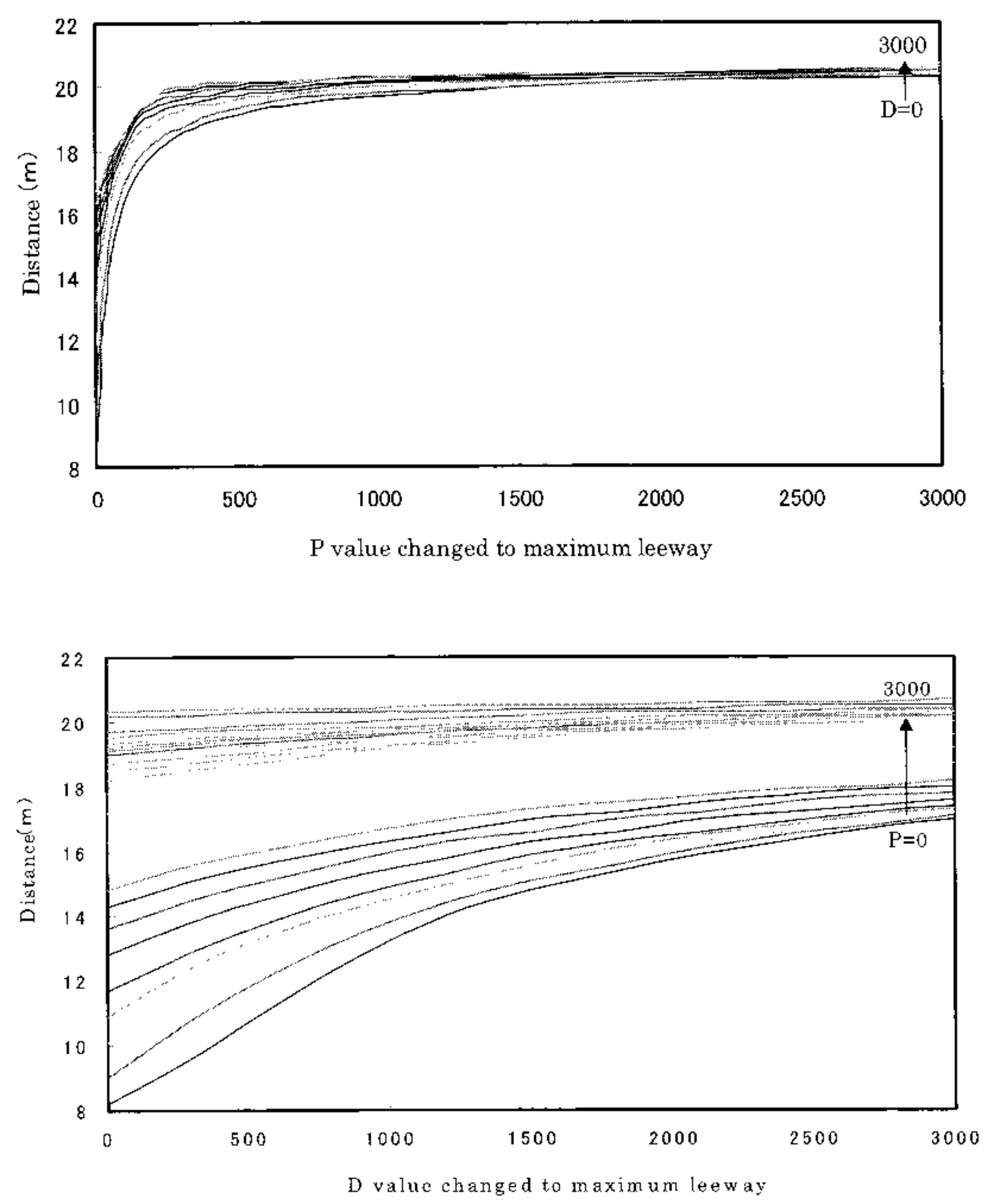

Fig. 2 Relation between distance and P-D value to maximum lee point

② Time to maximum lee point

The tendency of this time is observed in Fig. 3. As a whole, time extends if the combination of P-D becomes large. The minimum is 78 seconds of (P0, D0), while the maximum is 143 seconds.

If it changes in the place (0-200) where P value is small, most influences will be lost, even if they have a big effect on the change of time and P value. The change of D value has some influence on the variation of time. But, the influence becomes smaller when it is combined with a big P value.

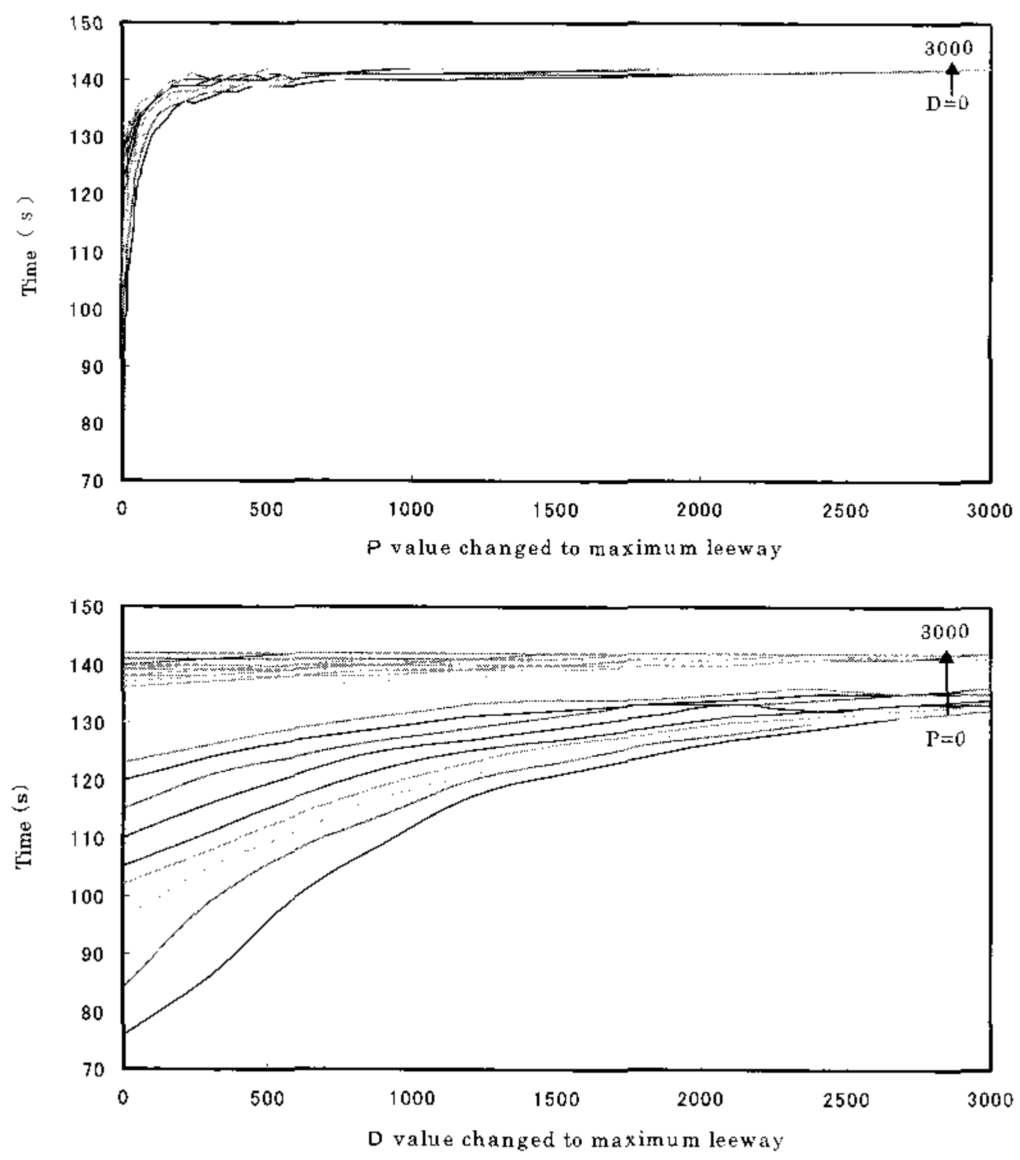

Fig. 3 Relation between time and P.D value to maximum lee point

We can summarize that the same tendency as time and distance to maximum lee point could be happened.

③ Time to return to original course

The distance from the original course, in data obtained , to each second is calculated as time, which shows the changing gap between the (+) sign on the right side and the (−) sign on the left. Its figure was rounded off when a decimal point was attached.

This time gets longer if the combination P-D value becomes larger. The minimum is 123 seconds of (P0, D0),

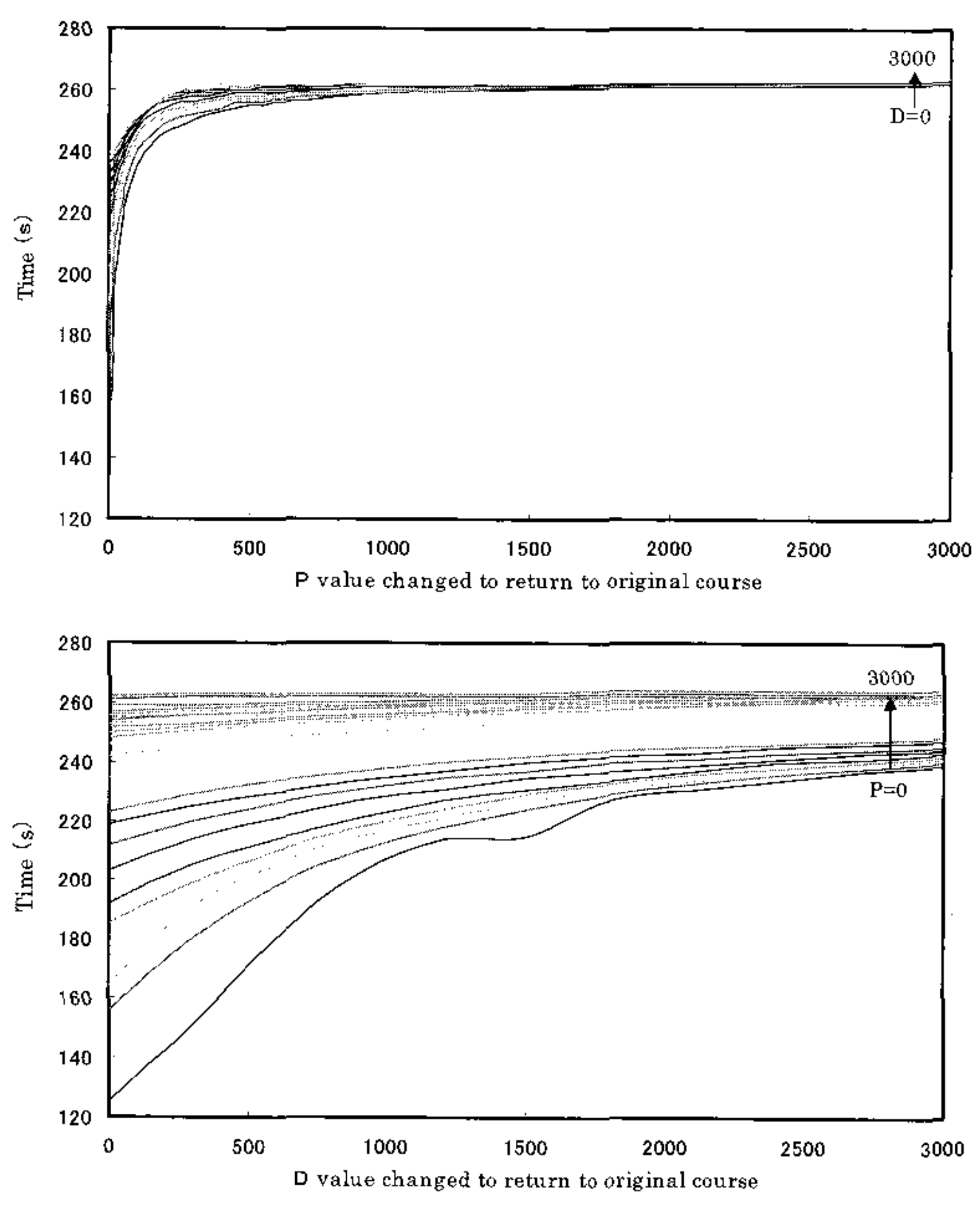

Fig. 4 Relation between time and P.D value to original course

and the maximum is 263 seconds.

If it changes in the place (0-200) where P value is small, as we noted a little earlier, most influences would be lost, even if there is a big influence on the change of time and P value.

④ Distance to the 300th second

Fig. 5 shows the distance in which a ship positions at the 300th second from its original course.

We cannot observe that a gap on the right side of the original course became smaller when a ship operator took the rudder. The distance will become shorter if the combination P-D value becomes higher in this simulation.

The minimum is 11.8m of (P3000, D3000), and the maximum is 101.2m of (P0, D0). If it changes in the place (0-60) where P value is small, it has some influence on the variation of distance. In particular, it will have a very big influence if the P value changes by (0-10). But, most influences are lost over more than 60 of P value. Change of the D value hardly affects the change of distance. When D value is less than 1000 at the time of combination with a small P value, it affects the distance.

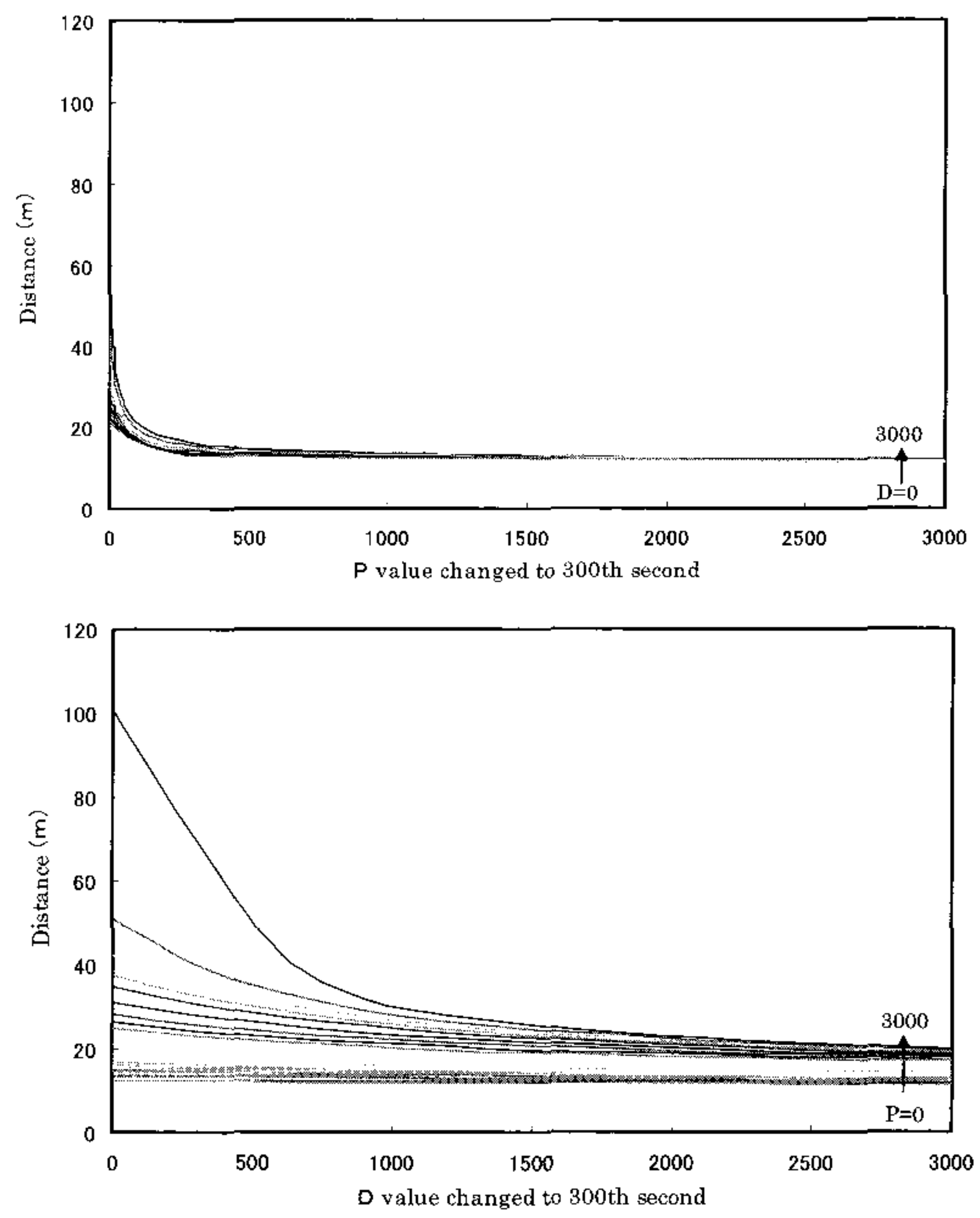

Fig. 5 Relation between distance and P.D value to 300th second

This tendency was different from the other three parameters. It means that the influence of P value is larger than D value of the distance from the 300th second point to the original course. This relation becomes remarkable when the combination of P-D value is very small. Moreover, the breadth of change is also wider than the other three indices.

From reasons mentioned above, it seems reasonable to suppose following. Though a ship is distrainted on its leeward side by wind pressure, in the case of this simulated condition, it becomes clear that the bow of the ship moves forward on the windward side.

If P and D values are small, the distance to the maximum lee point, the time to the maximum lee point, and the time to return to its original course will all become shorter. That is identified as it becomes easy to mark the forward movement on the windward side.

Therefore, it could be difficult to carry out the heading maintenance navigation sensitively, owing to the small P and D value.

Otherwise, if these values are large, the distance and time to the maximum lee point as well as the time to return to its original course will become longer, too.

4.2 Estimation of effective rudder handling under wind pressure

According to the relation mentioned previously, permissible transfer (m) is set to 15m. The 15m comes to the width of half of the PCC's beam. The combination P and D value for this transfer(m) is found among the indices of distance to maximum lee point. In addition, the combination of these values is applied to the other three parameters.

Fig. 6 indicates the response of rudder angle according to time from the data of combination P-D value. The sensitivity of the rudder angle is considered as the speed of angle reaches 35 degrees hard. Therefore, we need to check when the P-D combination is first at 35

degrees. It means that a rudder angle to be earliest at 35 degrees is the most sensitive P-D combination.

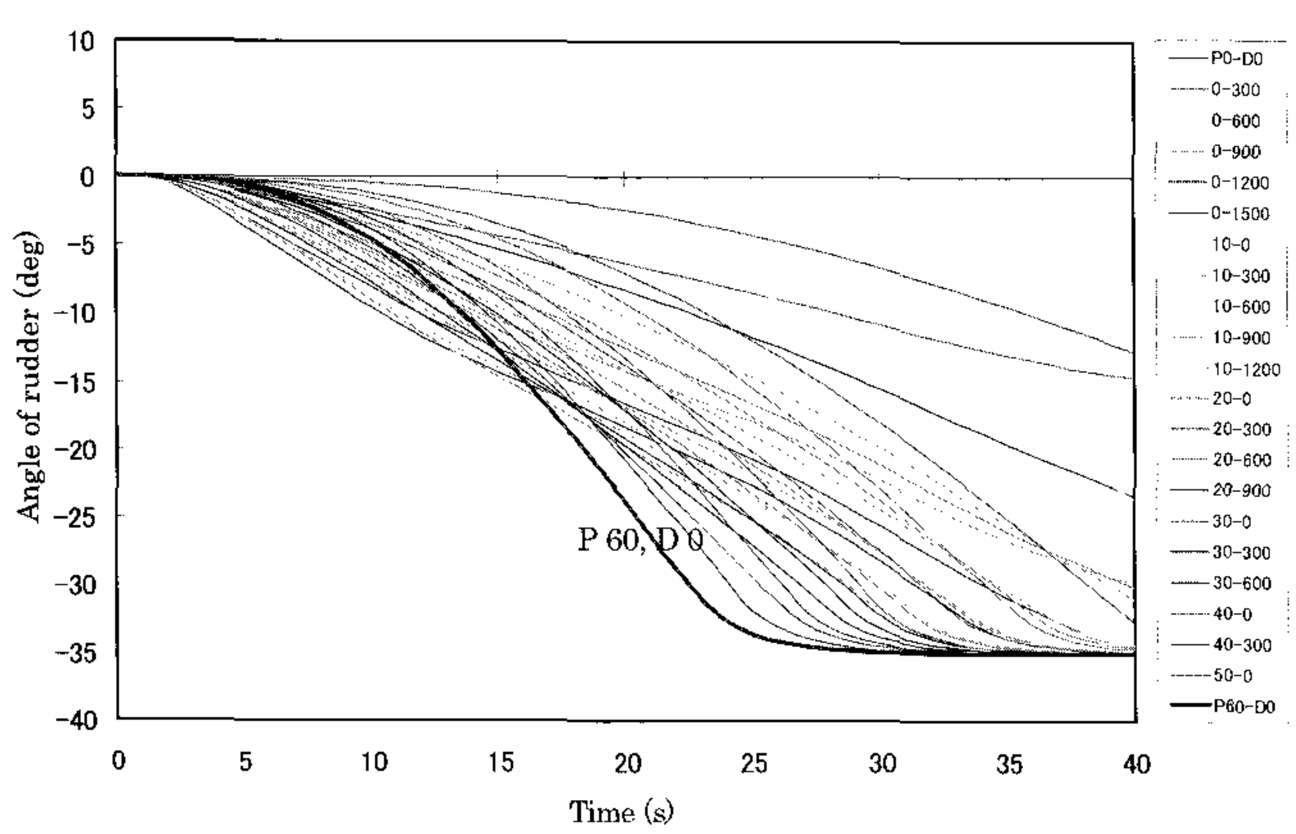

Fig. 6 Response of rudder angle according to time

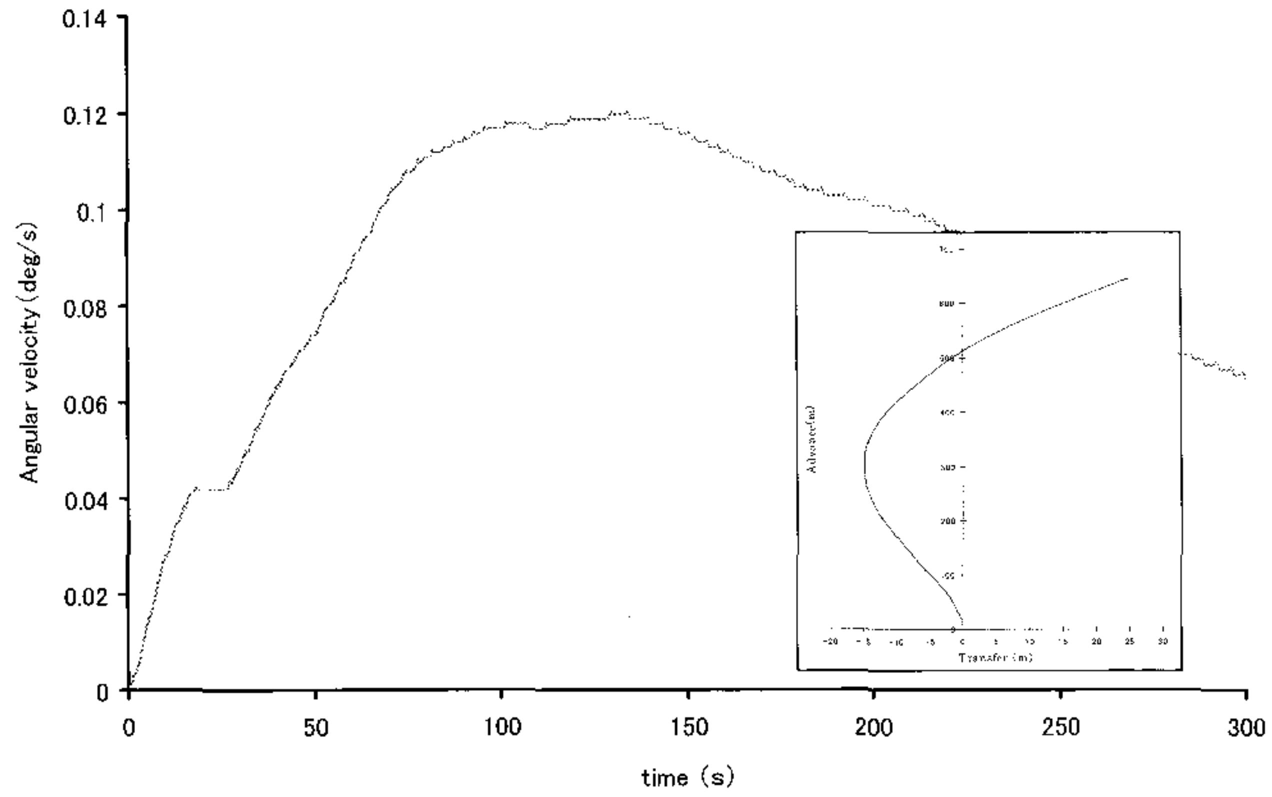

Fig. 7 Change of angular velocity and its relation between transfer and advance in P60, D0

It shows that the combination of (P60, D0) is to be the earliest. Therefore, we can judge that this is the most sensitive combination that can be performed within the permissible Transfer (m).

Fig 7 indicate ship's tracks and the angular velocity in (P60, D0). It show the maximum angular velocity to be below 0.12 (deg/s).

5. Conclusion

This research generated four parameters by reproduceing the movement of a PCC and these indices could provide guidance in low-speed navigation. Throughout the simulation and investigation of the P-D combination, We know that (60-0) of P-D value is most suitable under these cases of simulation. That is, sensitive navigation can be carried out within the permissible transfer (m) according to this combination. As a result, we think that this index, like formulated P-D, leads to an easy and safe navigation by utilizing these indices.

For future research, this next step is necessary.

(1) A more detailed index from further research in the combination of other wind direction and forces.

(2) In order to remove the steady error of autopilot, an index of course maintenance navigation can also be considered by calculating I value as the object of these combinations.

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Appendix

This research used the MMG(mathematical Modelling Group) model to simulate hull movement under wind pressure. The simulation of navigation was embodied by using this control model. The external forces X, Y and moment N consist of hull, propeller, rudder and wind components that are · noted with subscripts H, P, R and W respectively.

$$(m+m_x)\dot{u}-(m+m_y)vr = X_H + X_P + X_R + X_W$$
$$(m+m_y)\dot{v}-(m+m_x)ur = Y_H + Y_P + Y_R + Y_W$$
$$(I_{zz}+i_{zz})\dot{r} = N_H + N_P + N_R + N_W$$

m_x, m_y Ship' mass

I_{zz} Moment of inertia of ship

u, v, r Velocity and angular velocity of ship

The coefficients (C_x, C_y, C_m) of wind force were derived and calculated from Yamano's data. And this research computed the wind force and relation acting on ship's hull with the following equations.

$$F_x = (1/2)C_x \rho A_x U^2$$
$$F_y = (1/2)C_y \rho A_y U^2$$
$$N_m = (1/2)C_m \rho A_{oa} U^2$$

$$C_x = C_{x0} + C_{x1}\cos\theta_w + C_{x2}\cos 2\theta_w + C_{x3}\cos 3\theta_w + C_{x4}\cos 4\theta_w + C_{x5}\cos 5\theta_w$$
$$C_y = C_{y1}\sin\theta_w + C_{y2}\sin 2\theta_w + C_{y3}\sin 3\theta_w$$
$$C_m = 0.1(C_{m1}\sin\theta_w + C_{m2}\sin 2\theta_w + C_{m3}\sin 3\theta_w)$$

F_x Wind force of x axis

F_y wind force of y axis

N_m Moment of wind force

U Relative wind velocity

ρ Mass density of air

A_x Fore face of effective projected area

A_y Side face of effective projected area

X_G Distance between ship's center of gravity

θ_w Relative wind direction from heading way

Table 3 Coefficient of wind force and moment (L=Loa)

C_x	Const.	A_y/L^2	X_G/L	L/B	A_y/A_x
C_{x0}	-0.0358	0.925	0.0521		
C_{x1}	2.58	-6.087		-0.1735	
C_{x2}	-0.97		0.978	-0.0556	
C_{x3}	-0.416			-0.0283	0.728
C_{x4}	0.0851			-0.0254	0.0212
C_{x5}	0.0318	0.287		-0.0164	
C_y	Const.				
C_{y1}	0.509	4.904			0.022
C_{y2}	0.0208	0.230	-0.075		
C_{y3}	-0.357	0.943		0.0381	
C_m	Const.				
C_{m1}	2.650	4.634	-5.876		
C_{m2}	0.105	5.306			0.0704
C_{m3}	0.616		-1.474	0.0161	

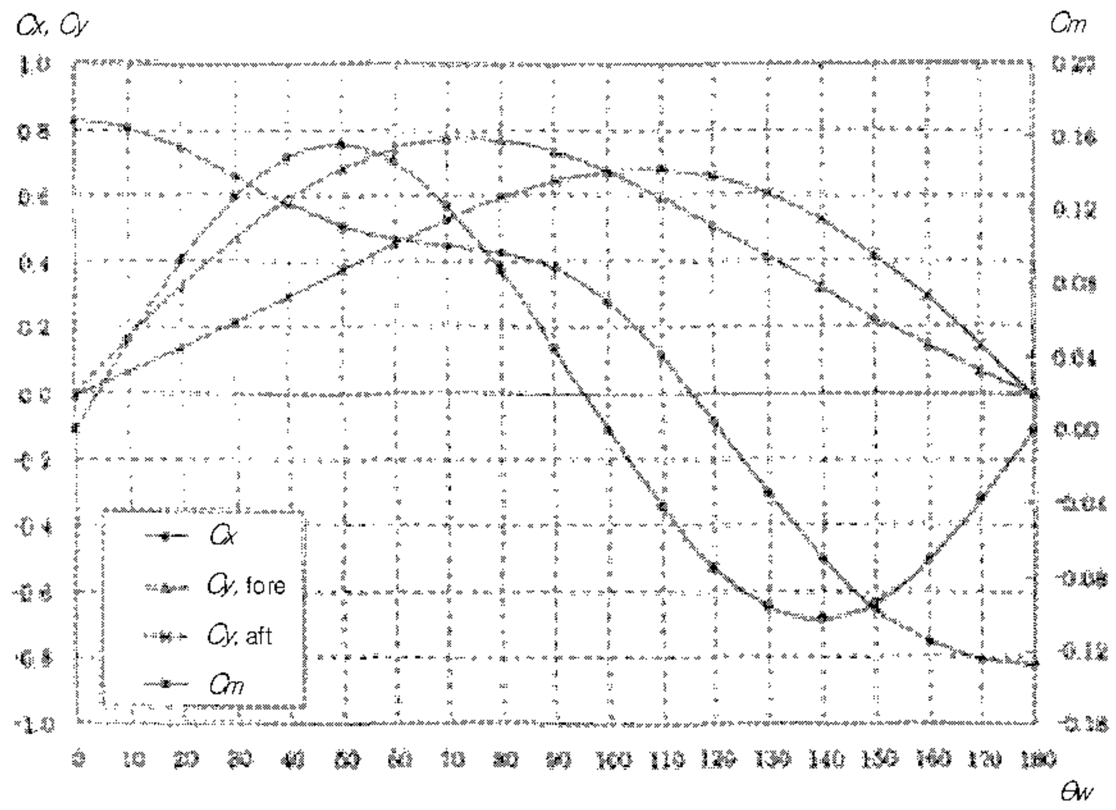

Fig. 8 Wind force and moment coefficient of 4,500 Units PCC (*Data from Yamano T.*)

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