

第35回セーリングヨット研究会

V P P から タッキングシミュレーションへ

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VPPでは

- 定常帆走状態を求める。
(力とモーメントが釣り合った状態)

- 連立方程式を解く。
(非線形の連立方程式になるため、
ニュートン・ラプソン法などを用いる)

運動シミュレーションでは(1)

- ・ 定常帆走状態から何かが変わった。
(例えば、風が強くなった、舵を切った)
- ・ 力やモーメントが釣り合わなくなる。
(力が変化したら 加速度が)
(モーメントが変化したら 角加速度が)

運動シミュレーションでは(2)

- 加速度を1回積分すると、速度に。
もう1回積分すると、距離(座標)に。
- 角加速度を1回積分すると、角速度に。
もう1回積分すると、角度に。
- この積分を時間を追って続けていくと、
例えば、舵を切った後に船がどのように
回頭していくかというような運動の
様子を表すことができる。

運動シミュレーションでは(3)

- ある瞬間に求められるのは加速度と角加速度。
- このため、運動を表す方程式は、微分方程式の形になる。
- 連立微分方程式を解くには、ルンゲ・クッタ法などが用いられる。

タッキングシミュレーションでは(1)

- V P P では考慮しなかった、運動による力やモーメントを求める必要がある。
- 一番大きな未知の力は、タッキング中のセール流体力の変化。
- この力の変化を「風神」によって実測し、タッキング中のセール流体力の変化をモデル化した。
- 新しいタッキングシミュレーション手法の提言を行う。

3rd High Performance Yacht Design Conference
Auckland, 2-4 December, 2008

Tacking Simulation of Sailing Yachts with New Model of Aerodynamic Force Variation

by

Yutaka Masuyama and Toichi Fukasawa
(Kanazawa Institute of Technology)

INTRODUCTION

We have been measuring sail shapes and performance of IMS type sail using sail dynamometer boat *Fujin*. We also performed numerical calculations using the measured sail shapes as input data.

In this report, we want to show the comparison of measured and calculated results. Moreover, we present the tables indicating sail performance and three-dimensional coordinates of the sail shape. These database will provide a good benchmark for further sail performance analysis.

Full scale sail test using sail
dynamometer boat *Fujin*

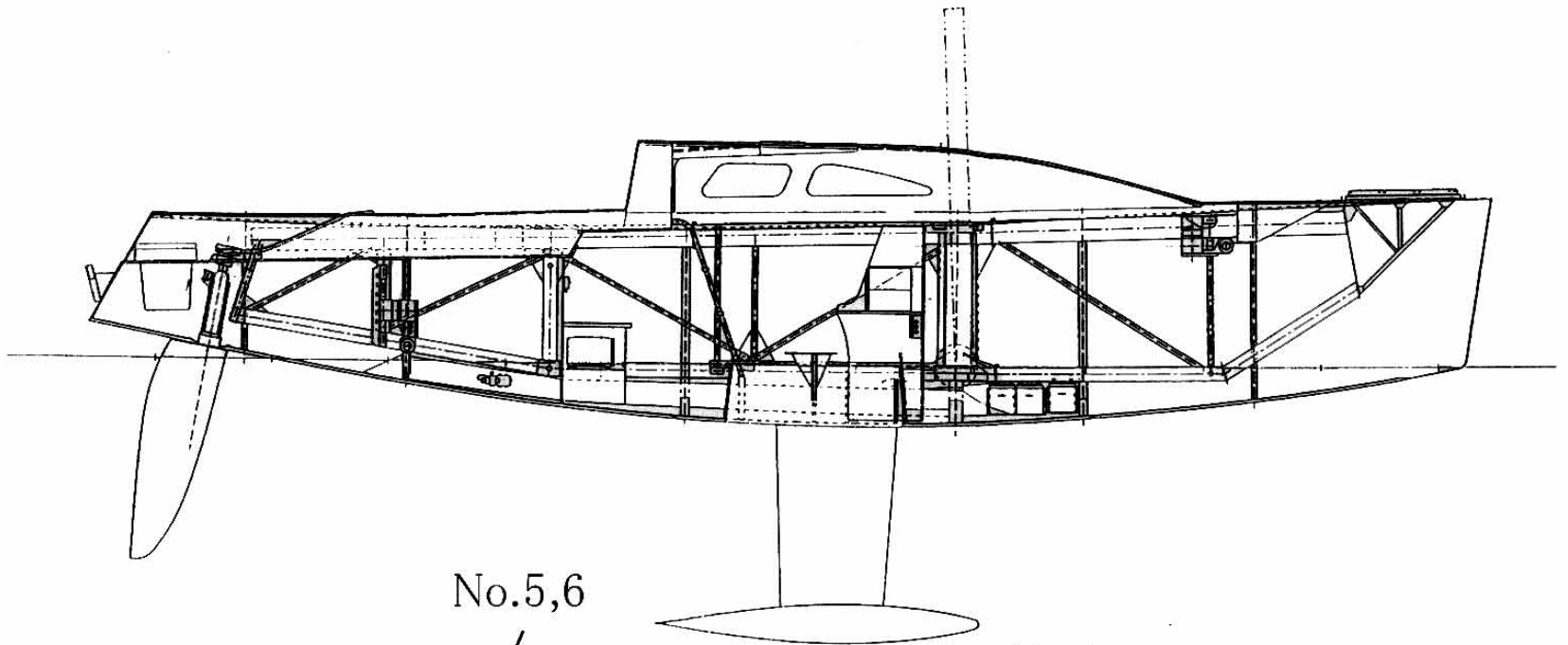
HULL		
LOA	[m]	10.35
LWL	[m]	8.80
BMAX	[m]	3.37
BWL	[m]	2.64
Disp	[ton]	3.86
SAIL		
I	[m]	11.00
J	[m]	3.61
P	[m]	12.55
E	[m]	4.51



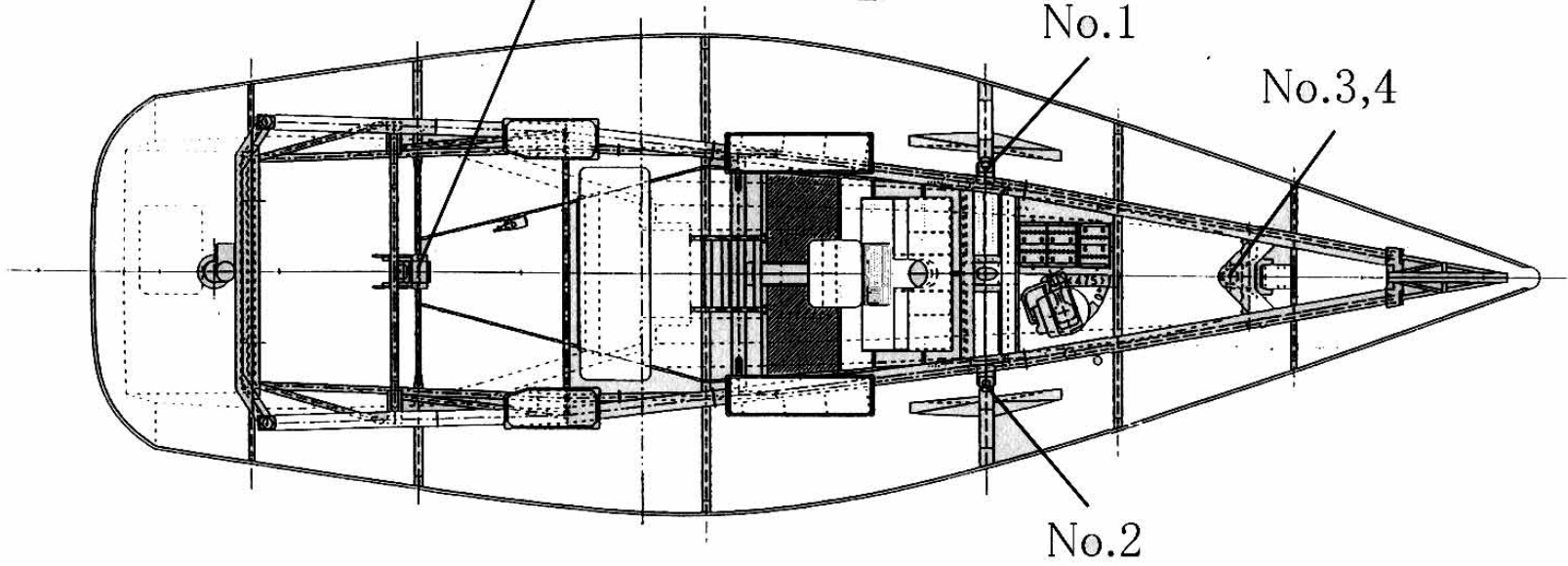
Principal dimensions and sail plan of *Fujin*



“*Fujin* = 風神” means “The God of the Wind”



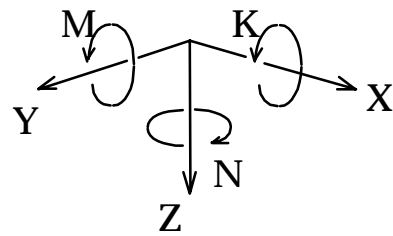
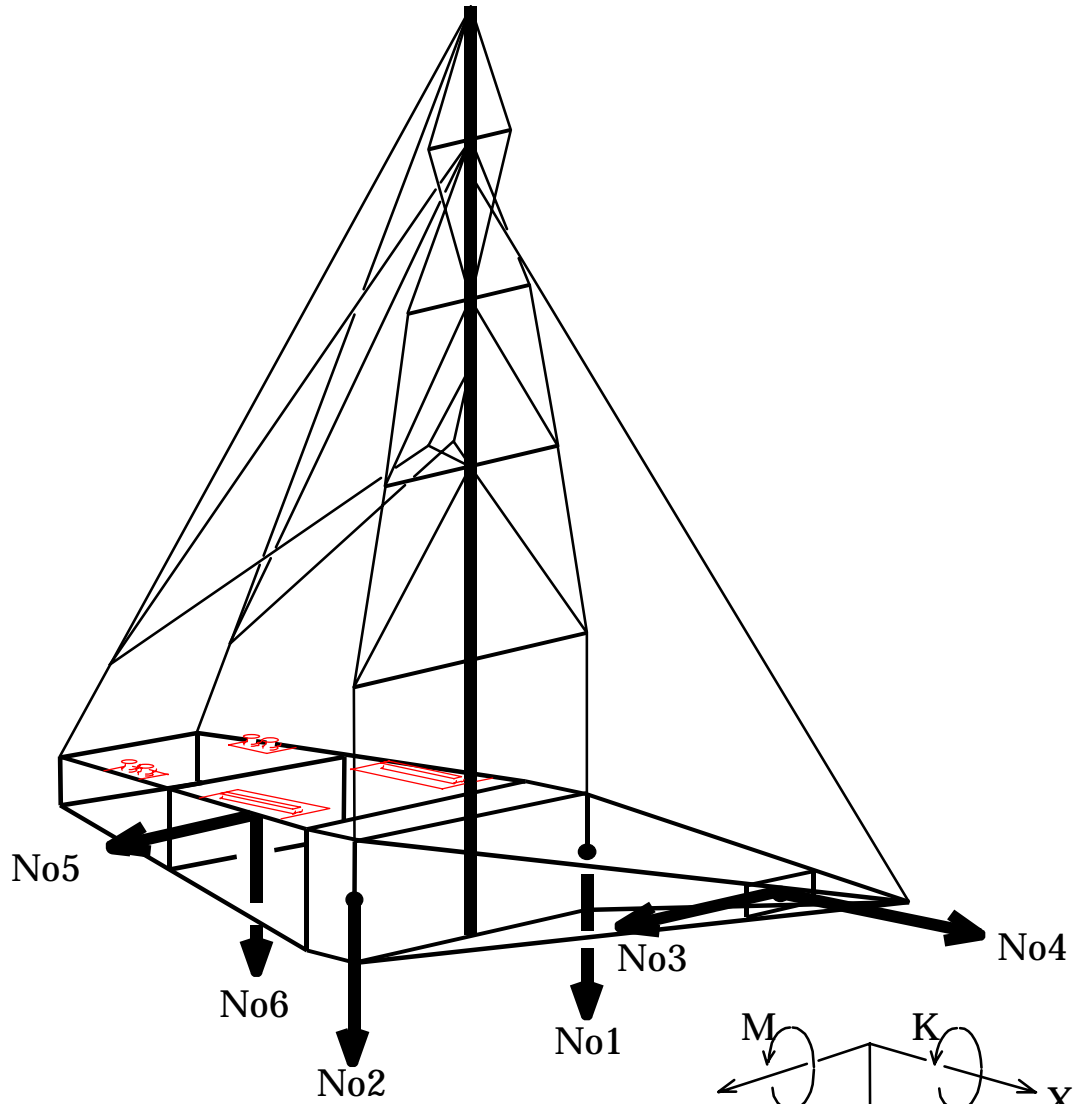
No.5,6



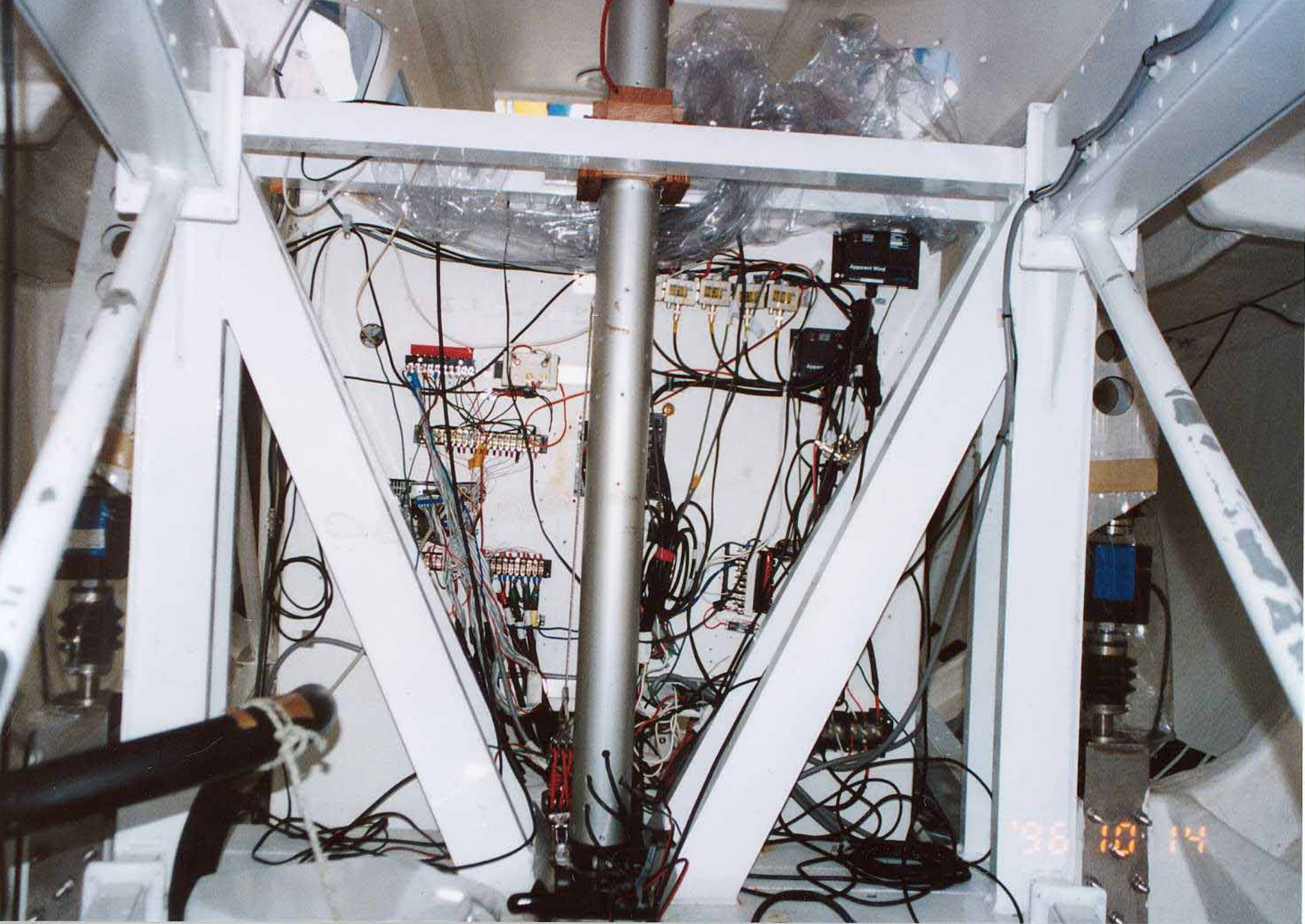
No.1

No.3,4

No.2





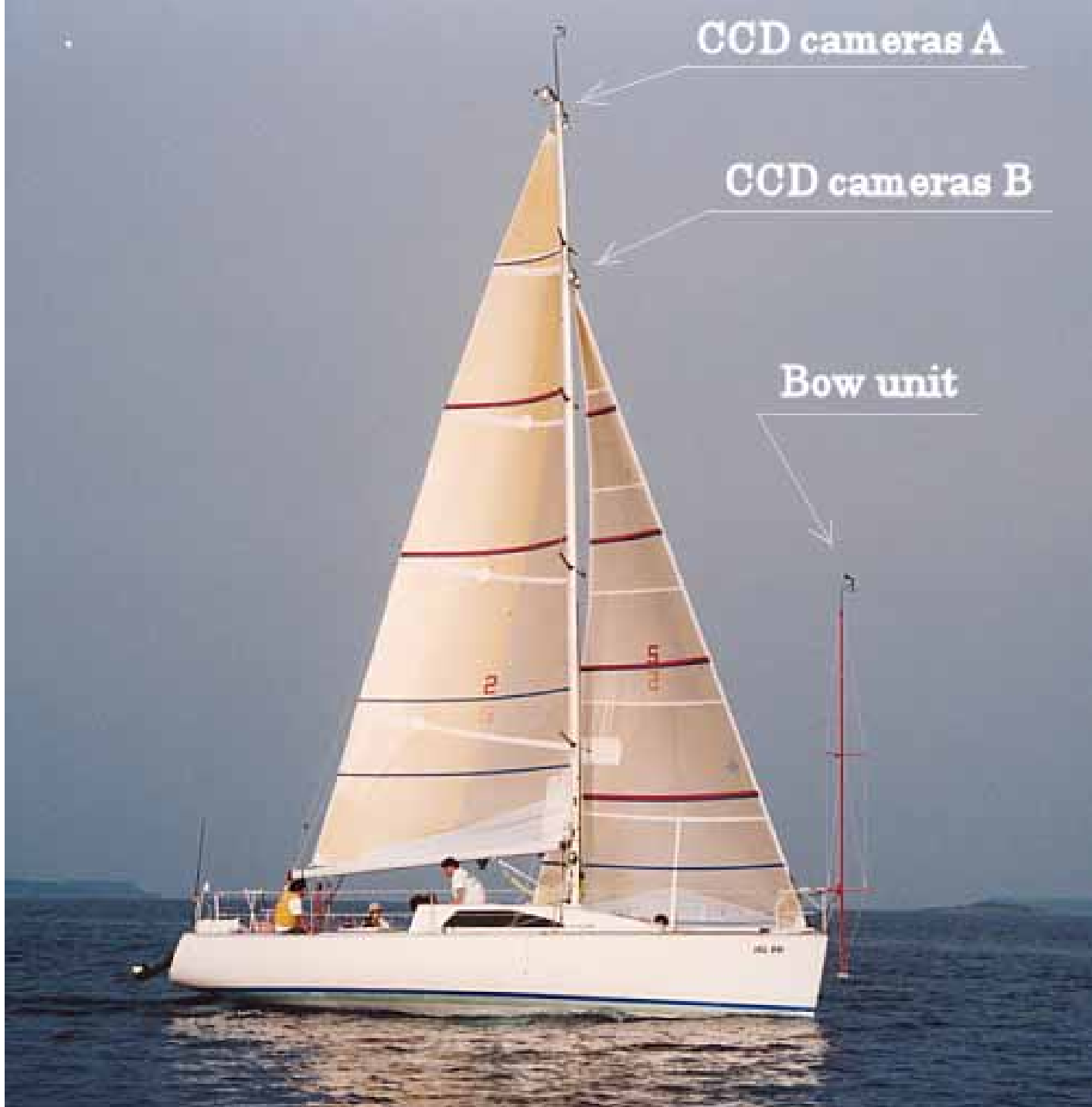




後

No. 3,4

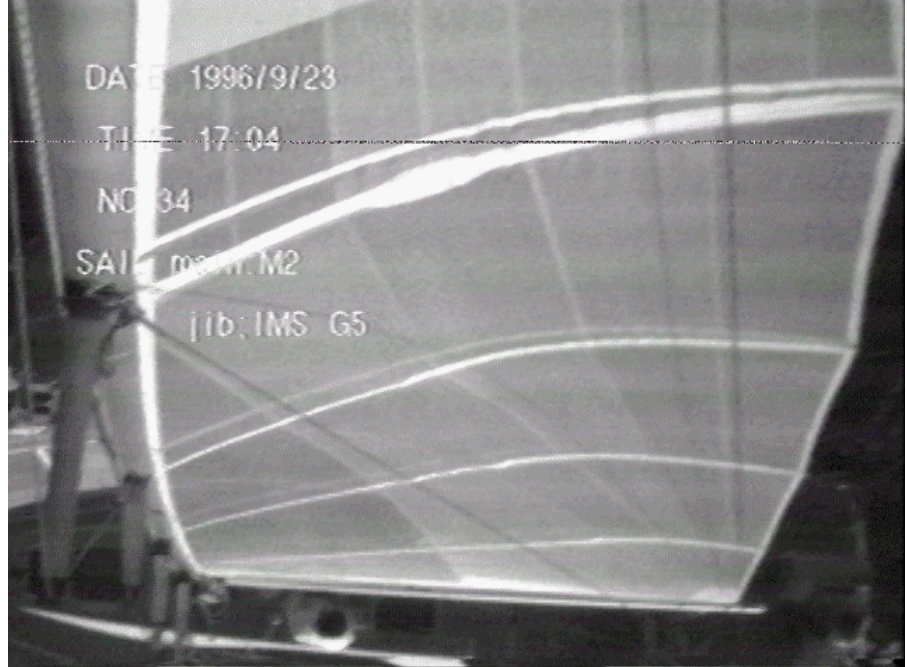
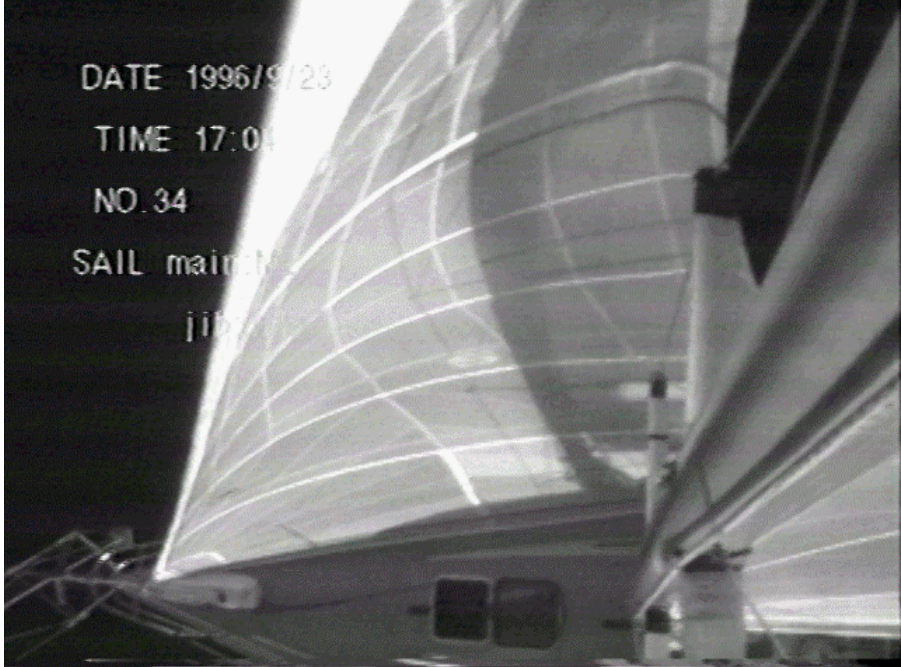
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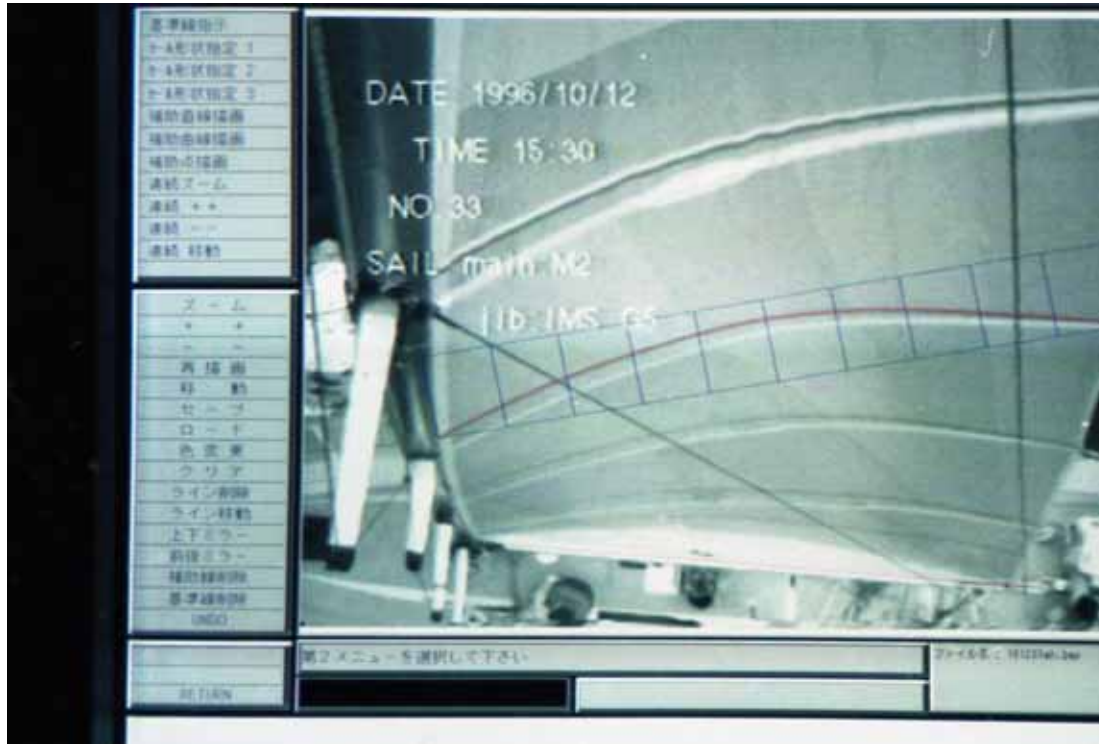
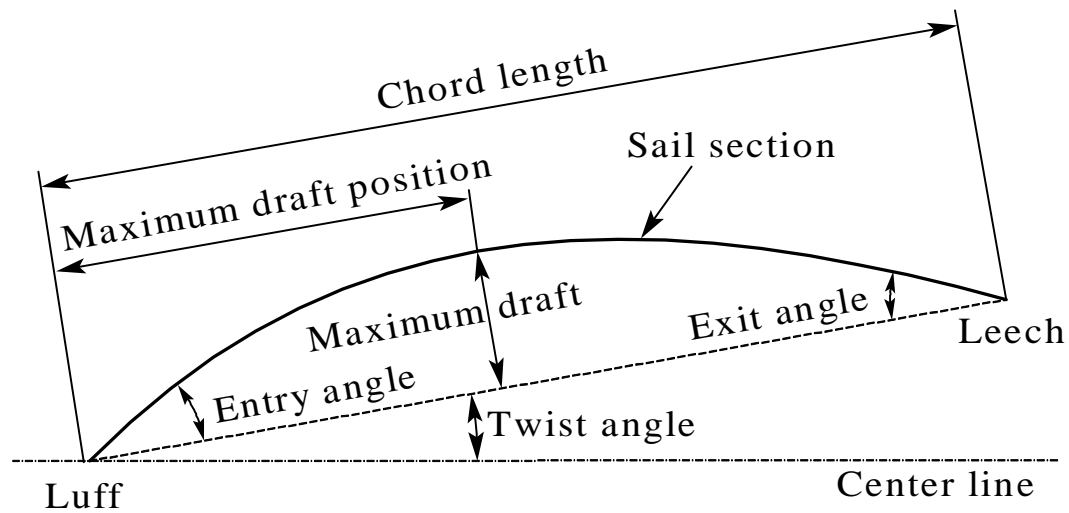
CCD cameras A

CCD cameras B

Bow unit



Sail shape images by CCD cameras



Sail shape image of SSA-2D and sail shape parameters



Mainsail Twist = 6.8°



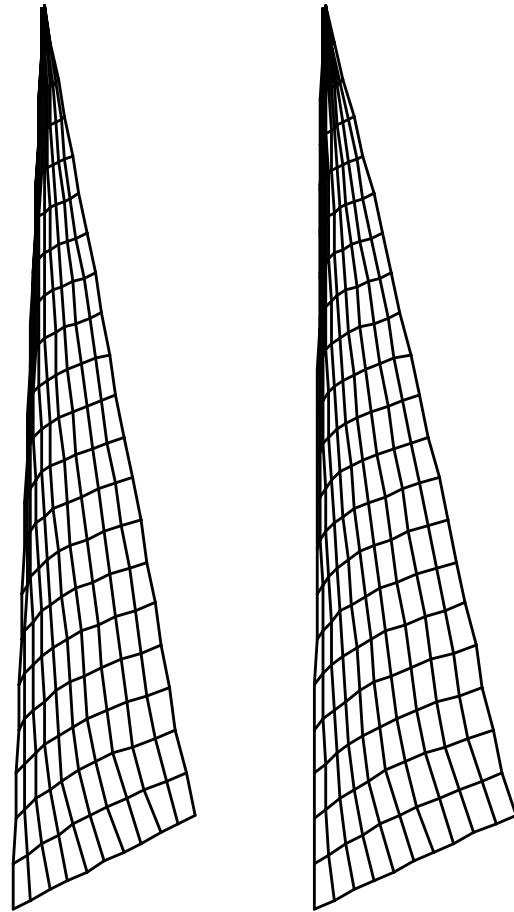
Mainsail Twist = 12.3°



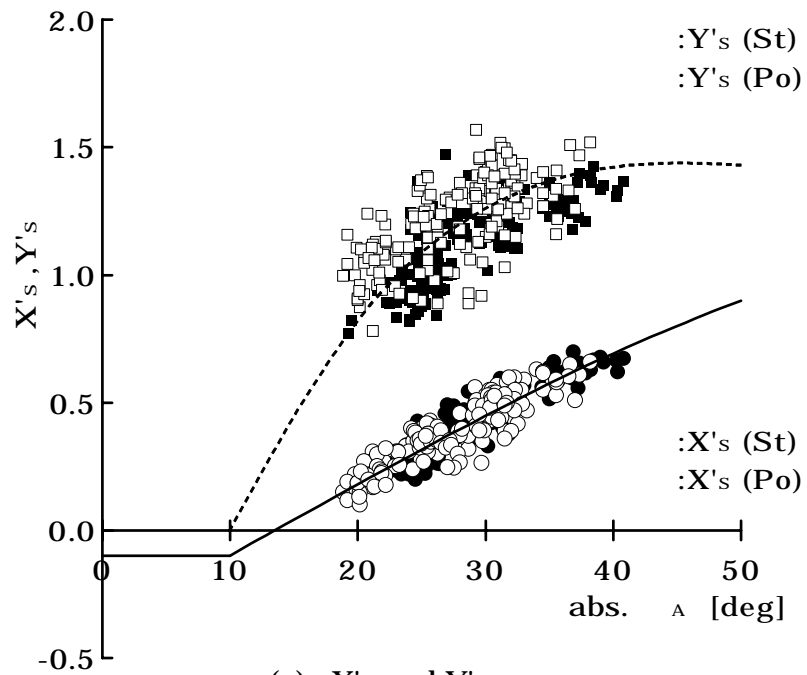
Mainsail Twist = 21.4°

(3) Variation with mainsail twist angle

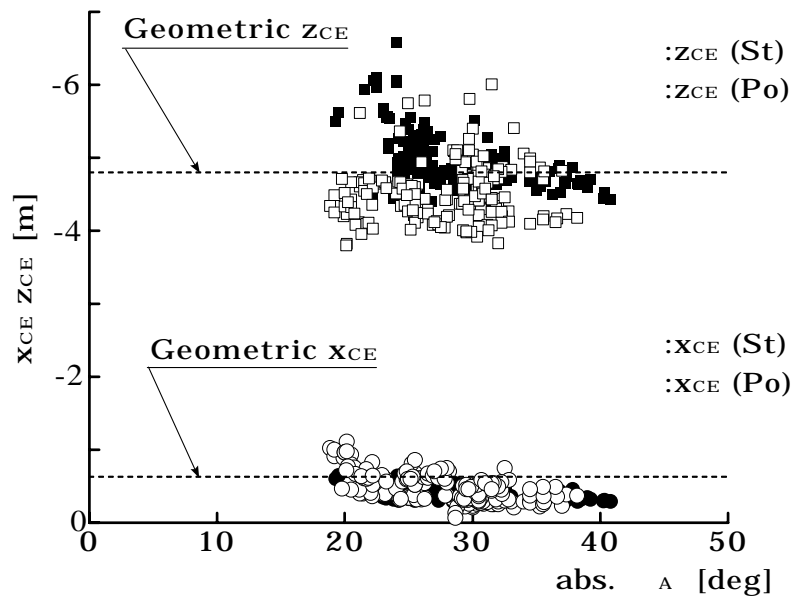
Can you see with stereoscopic view?



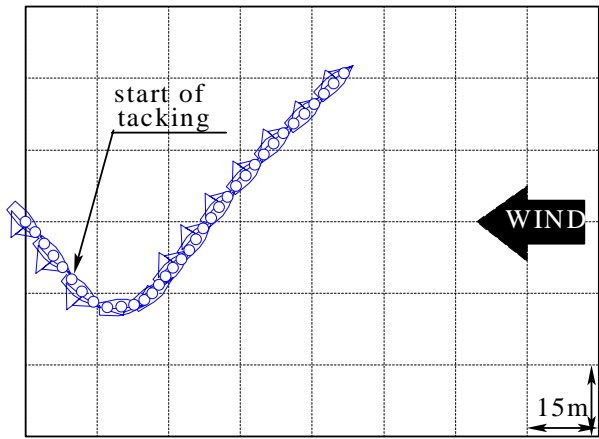
Measured mainsail shape



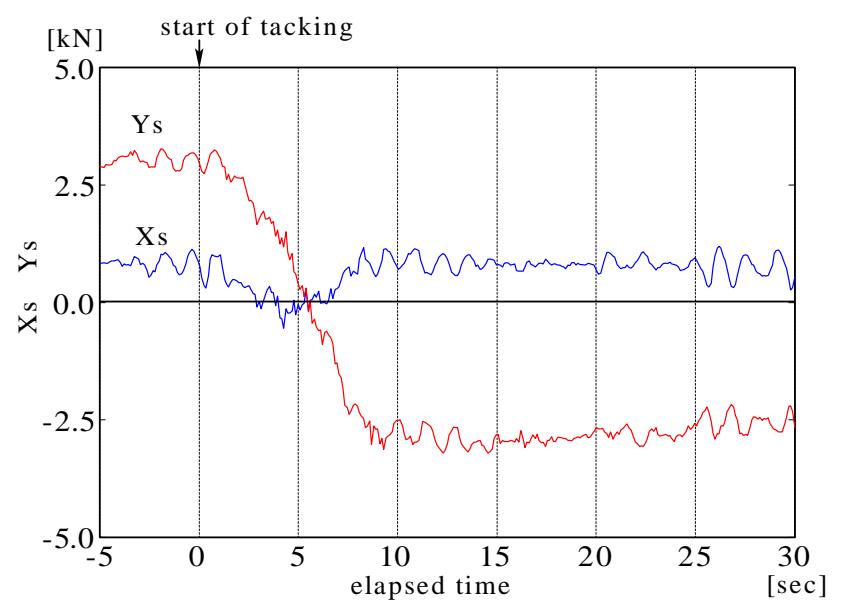
(a) $X's$ and $Y's$ vs. A



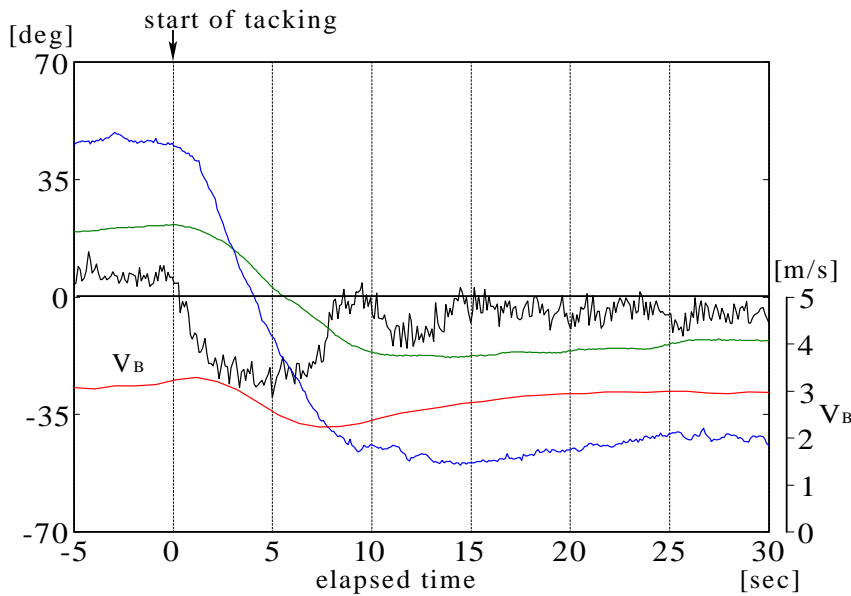
(b) x_{CE} and z_{CE} vs. A



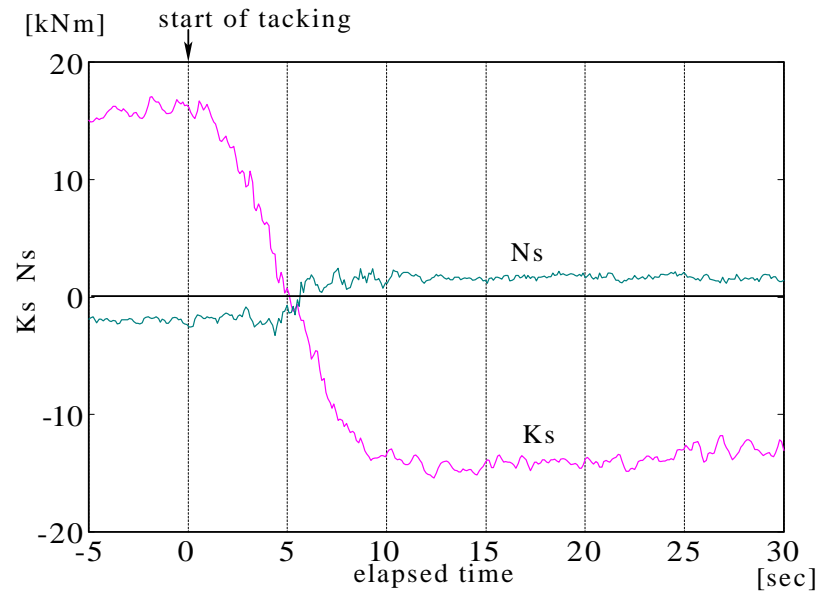
(a) Trajectory of boat



(c) Sail forces X_s, Y_s

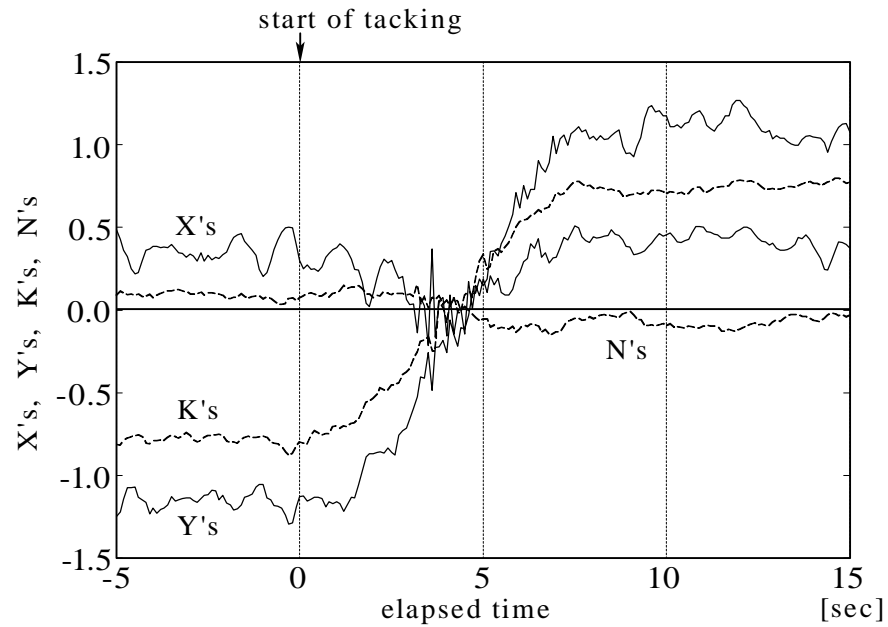


(b) Boat attitude parameters

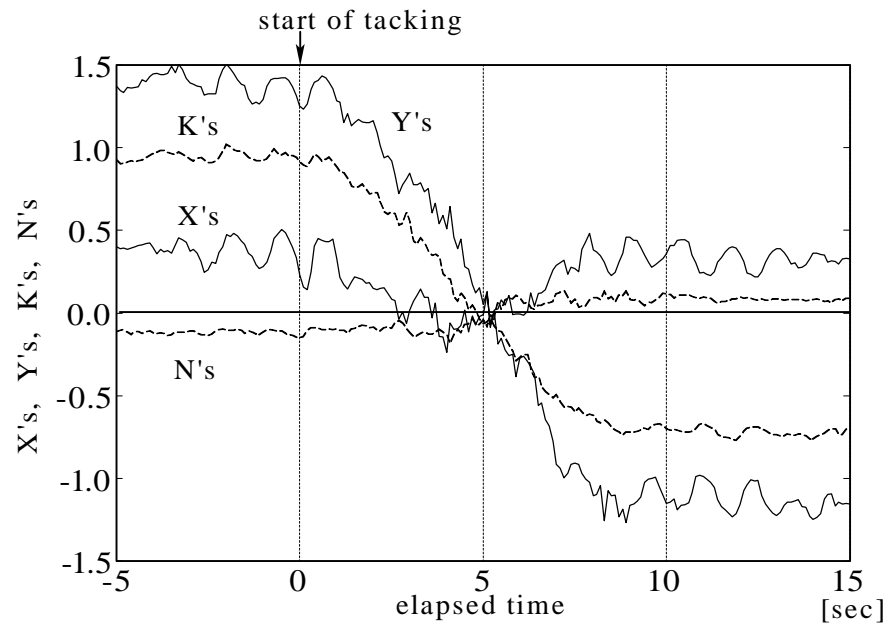


(d) Sail moments K_s, N_s

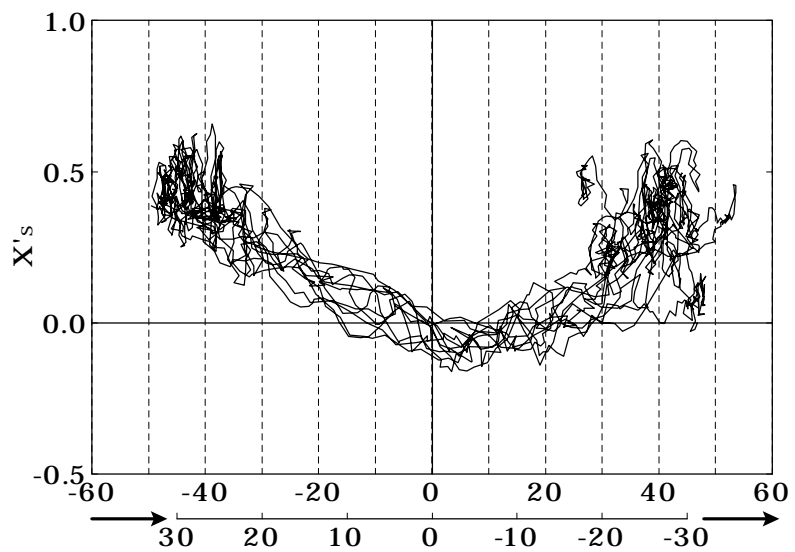
Fujin:07230BP Trajectory of boat and time histories of attitude parameters and sail forces during tacking maneuver from port to starboard tack (measured)



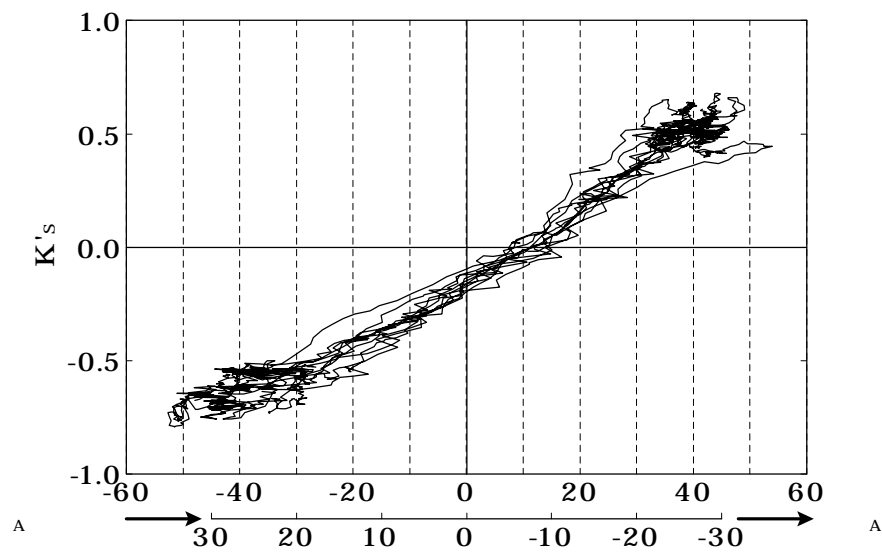
(a) Tacking from starboard tack to port tack



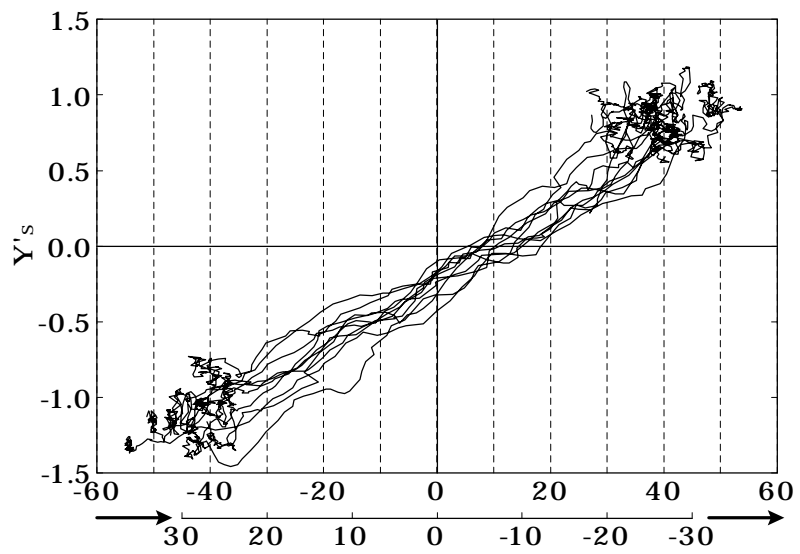
(b) Tacking from port tack to starboard tack



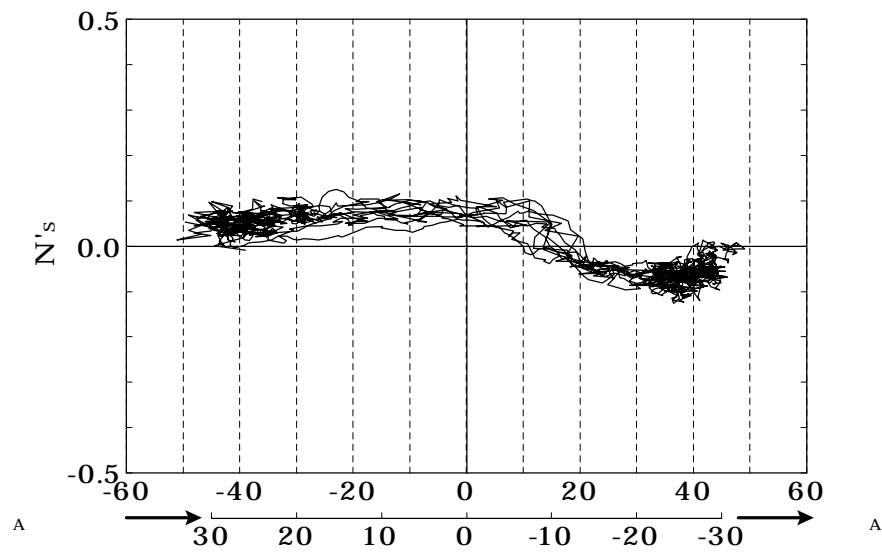
(a) X's vs. and A



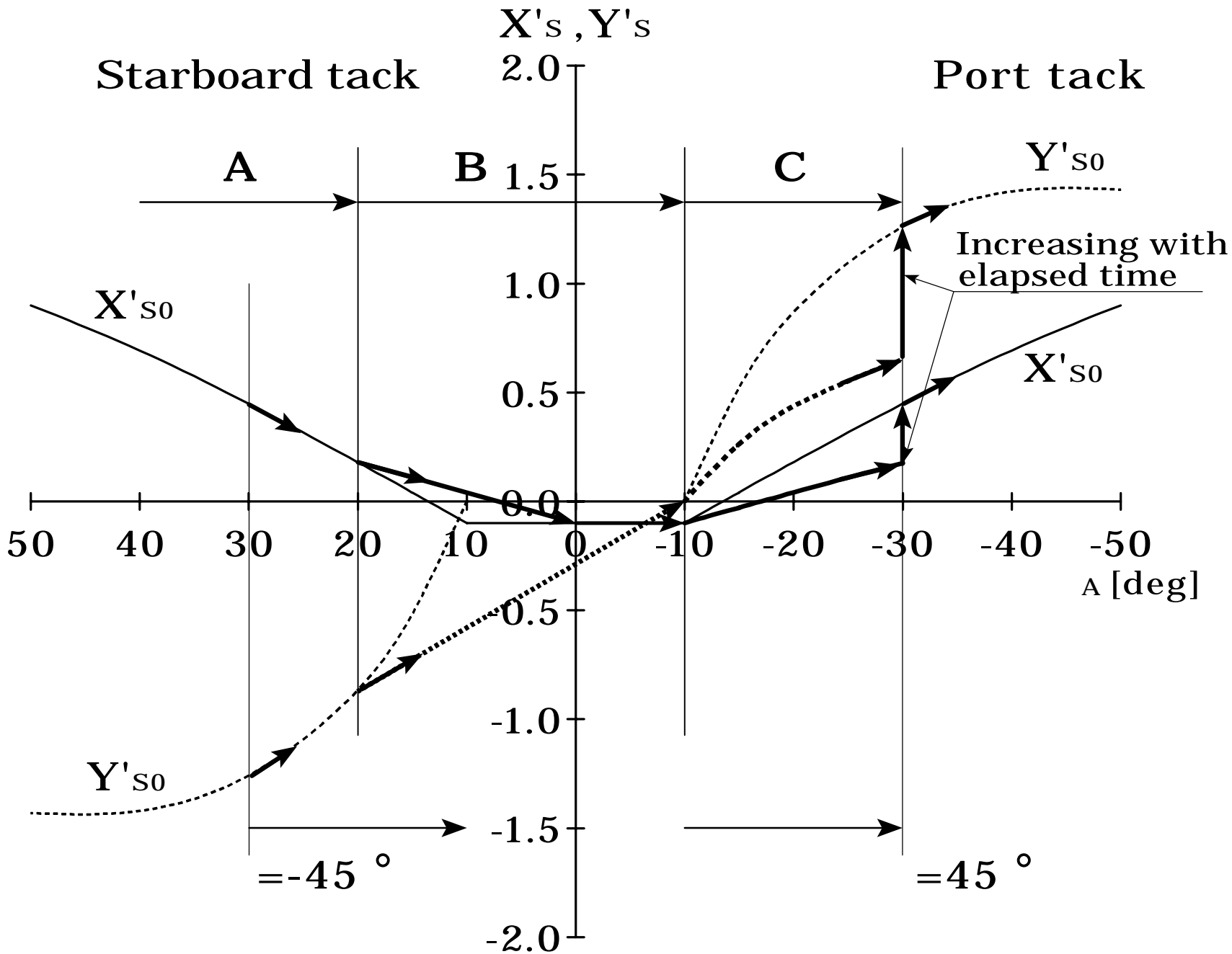
(c) K's vs. and A



(b) Y's vs. and A



(d) N's vs. and A



Equations of Motion for Numerical Equation

Surge:

$$(m + m_x)\dot{U} - (m + m_y \cos^2 \phi + m_z \sin^2 \phi)V\dot{\psi}$$
$$= X_0 + X_H + X_{V\dot{\psi}}V\dot{\psi} + \left(\frac{1}{2}\rho V_B^2 L D\right)X'_R + X_S$$

m : mass

m_x, m_y, m_z : added mass

u, v : velocity components along x and y-axis

X_0 : resistance at upright condition

Sway:

$$\begin{aligned} & (m + m_y \cos^2 \phi + m_z \sin^2 \phi) \dot{V} + (m + m_x) U \dot{\psi} \\ & + 2(m_z - m_y) \sin \phi \cos \phi \cdot V \dot{\phi} \\ & = Y_H + Y_{\dot{\phi}} \dot{\phi} + Y_{\dot{\psi}} \dot{\psi} + \left(\frac{1}{2} \rho V_B^2 L D\right) Y'_R + Y_S \end{aligned}$$

Roll:

$$\begin{aligned} & (I_{xx} + J_{xx}) \ddot{\phi} - \left\{ (I_{yy} + J_{yy}) - (I_{zz} + J_{zz}) \right\} \sin \phi \cos \phi \cdot \dot{\psi}^2 \\ & = K_H + K_{\dot{\phi}} \dot{\phi} + \left(\frac{1}{2} \rho V_B^2 L D^2\right) K'_R + K_S - mg \overline{GM} \sin \phi \end{aligned}$$

Yaw:

$$\begin{aligned} & \left\{ (I_{yy} + J_{yy}) \sin^2 \phi + (I_{zz} + J_{zz}) \cos^2 \phi \right\} \ddot{\psi} \\ & + 2 \left\{ (I_{yy} + J_{yy}) - (I_{zz} + J_{zz}) \right\} \sin \phi \cos \phi \cdot \dot{\psi} \dot{\phi} \\ & = N_H + N_{\dot{\psi}} \dot{\psi} + \left(\frac{1}{2} \rho V_B^2 L^2 D\right) N'_R + N_S \end{aligned}$$

Hydrodynamic Forces and Moments Acting on the Hull

$$X_H = (X_{VV}' V'^2 + X_{\phi\phi}' \phi^2 + X_{VVVV}' V'^4) \left(\frac{1}{2} \rho V_B^2 L D \right)$$

$$Y_H = (Y_V' V' + Y_\phi' \phi + Y_{V\phi\phi}' V' \phi^2 + Y_{VV\phi}' V'^2 \phi + Y_{VVV}' V'^3) \left(\frac{1}{2} \rho V_B^2 L D \right)$$

$$K_H = (K_V' V' + K_\phi' \phi + K_{V\phi\phi}' V' \phi^2 + K_{VV\phi}' V'^2 \phi + K_{VVV}' V'^3) \left(\frac{1}{2} \rho V_B^2 L D^2 \right)$$

$$N_H = (N_V' V' + N_\phi' \phi + N_{V\phi\phi}' V' \phi^2 + N_{VV\phi}' V'^2 \phi + N_{VVV}' V'^3) \left(\frac{1}{2} \rho V_B^2 L^2 D \right)$$

Where,

$$V' = -\frac{V_B \sin \beta}{V_B} = -\sin \beta$$

Hydrodynamic Forces and Moments Acting on the Rudder

$$X_R = C_{X\delta} \sin \alpha_R \sin \delta \left(\frac{1}{2} \rho V_B^2 L D \right)$$

$$Y_R = C_{Y\delta} \sin \alpha_R \cos \delta \cos \phi \left(\frac{1}{2} \rho V_B^2 L D \right)$$

$$K_R = C_{K\delta} \sin \alpha_R \cos \delta \left(\frac{1}{2} \rho V_B^2 L D^2 \right)$$

$$N_R = C_{N\delta} \sin \alpha_R \cos \delta \cos \phi \left(\frac{1}{2} \rho V_B^2 L^2 D \right)$$

Where, $\alpha_R = \delta - \gamma_R \cdot \beta - \tan^{-1} \left(\frac{l_R \dot{\psi}}{U} \right)$

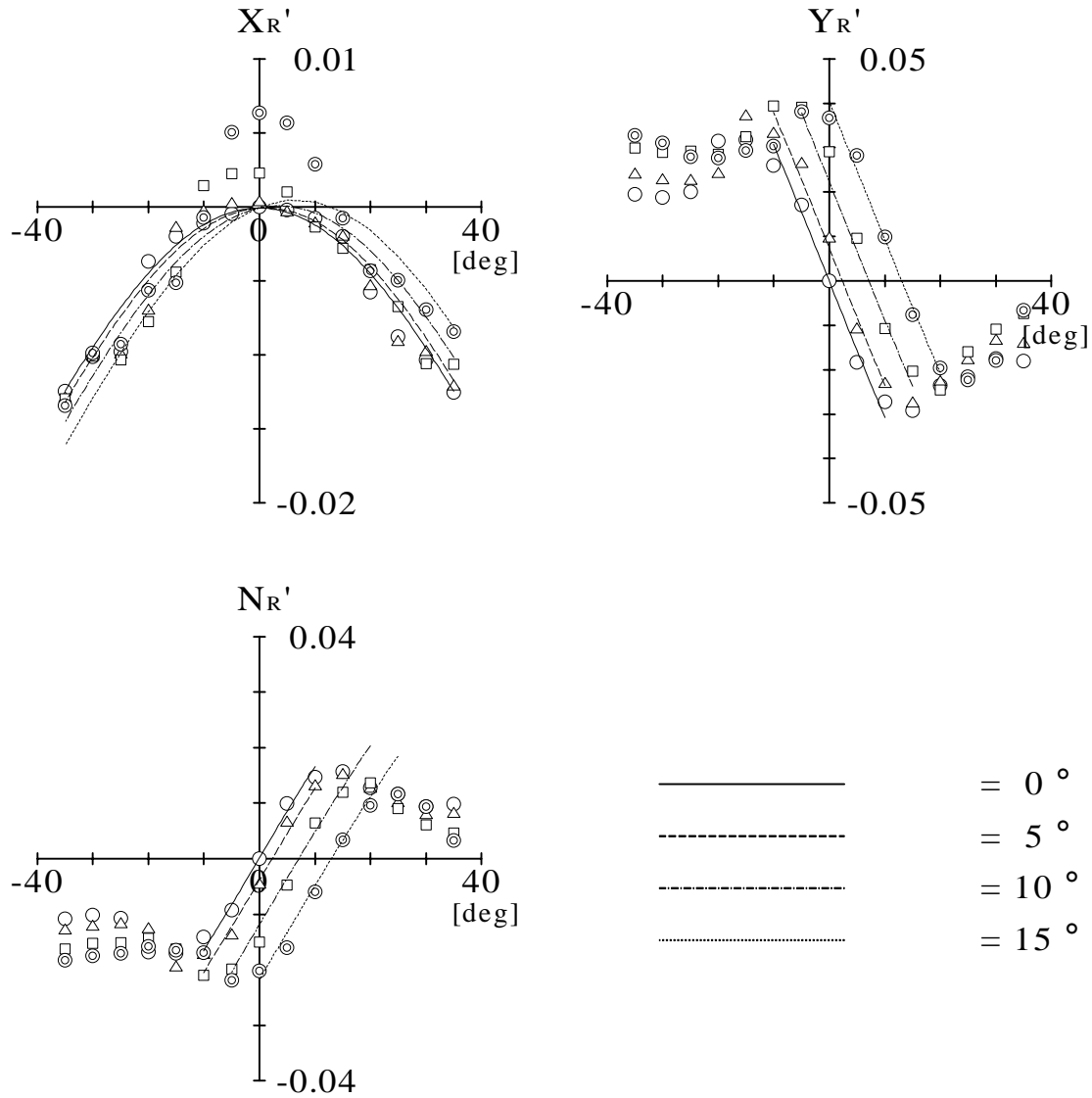


Figure Variation of hydrodynamic coefficients of rudder with rudder angle for *Fujin*

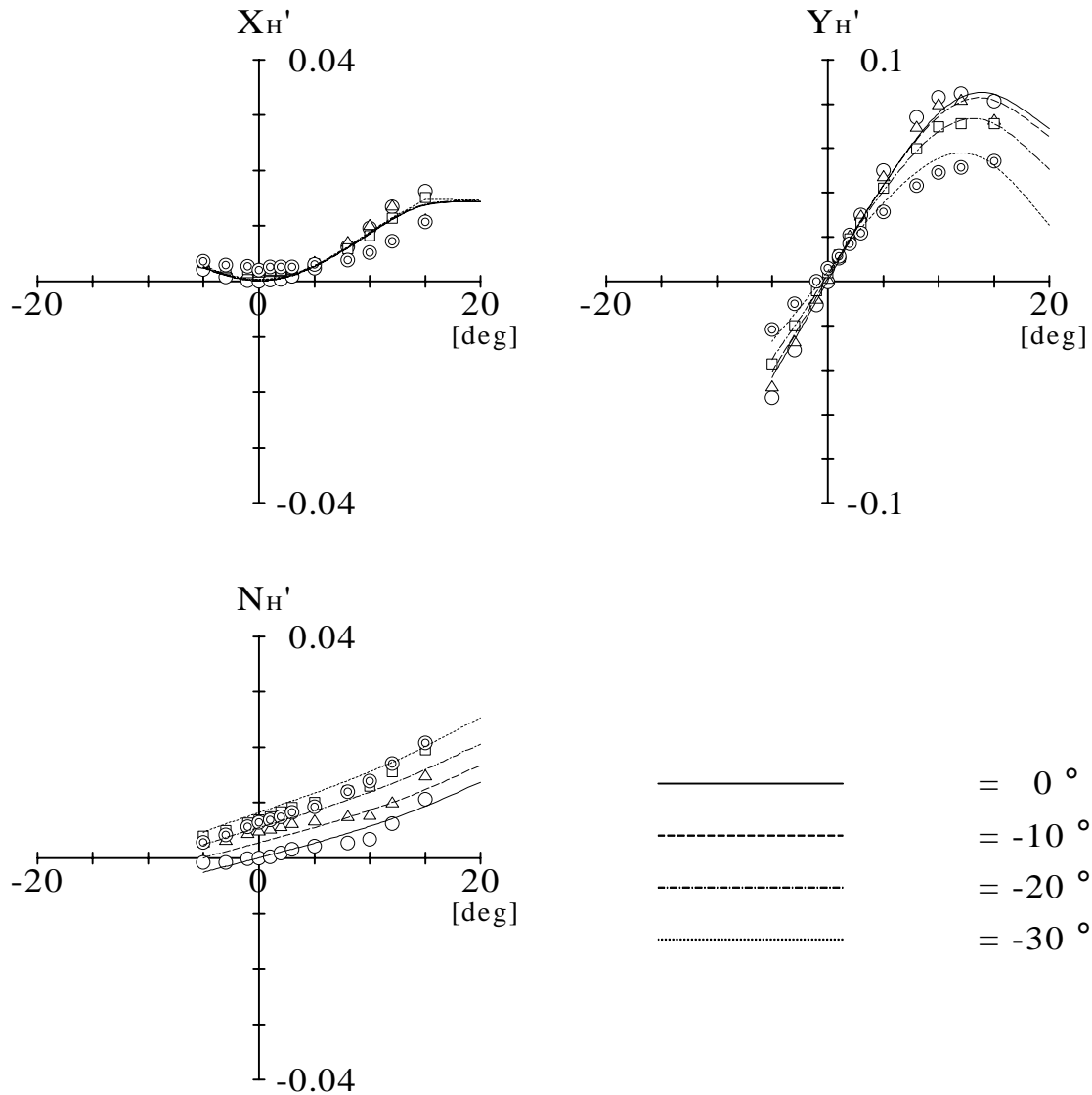
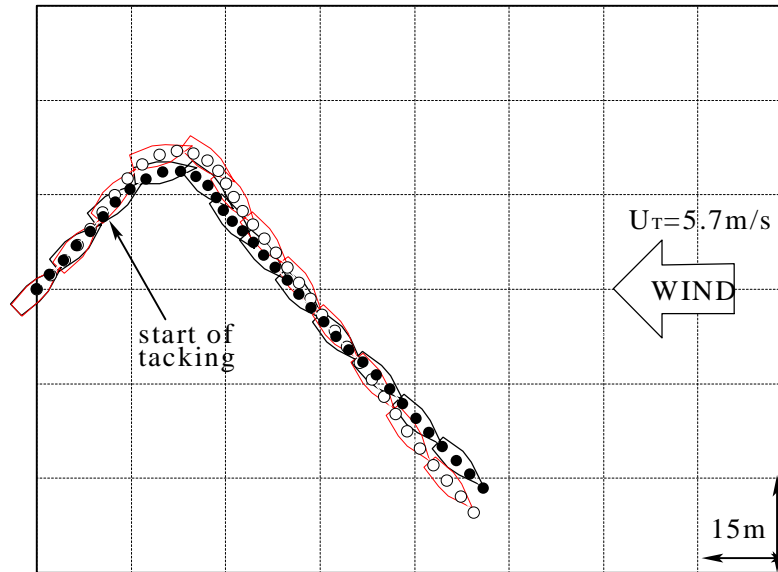
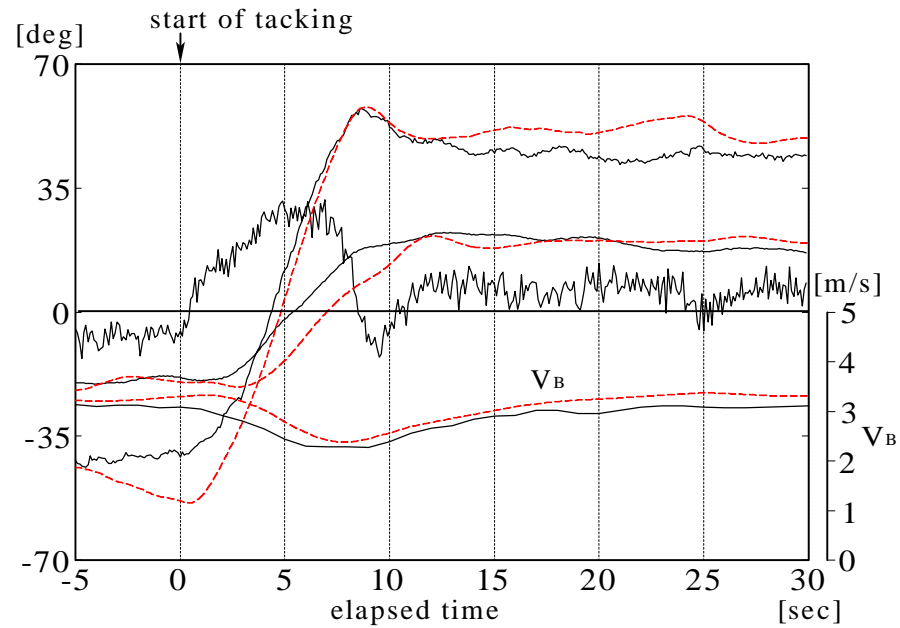


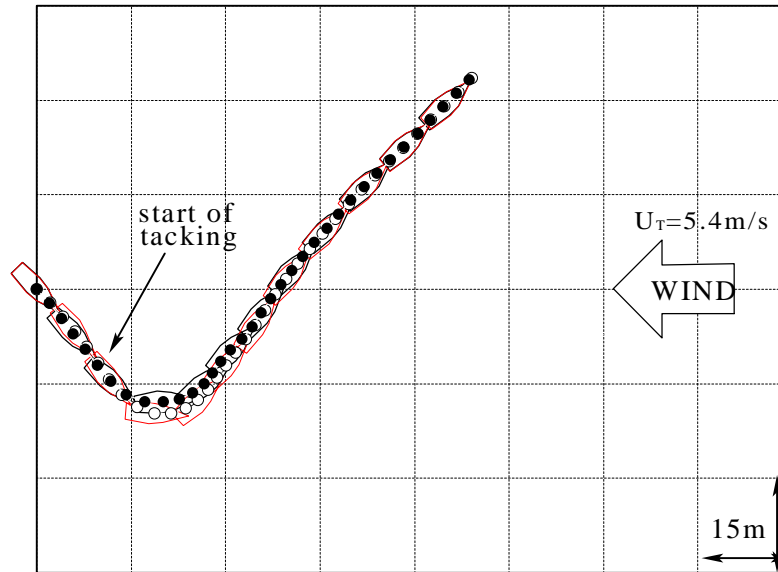
Figure Variation of hydrodynamic coefficients of hull with leeway angle for *Fujin* (without rudder forces)



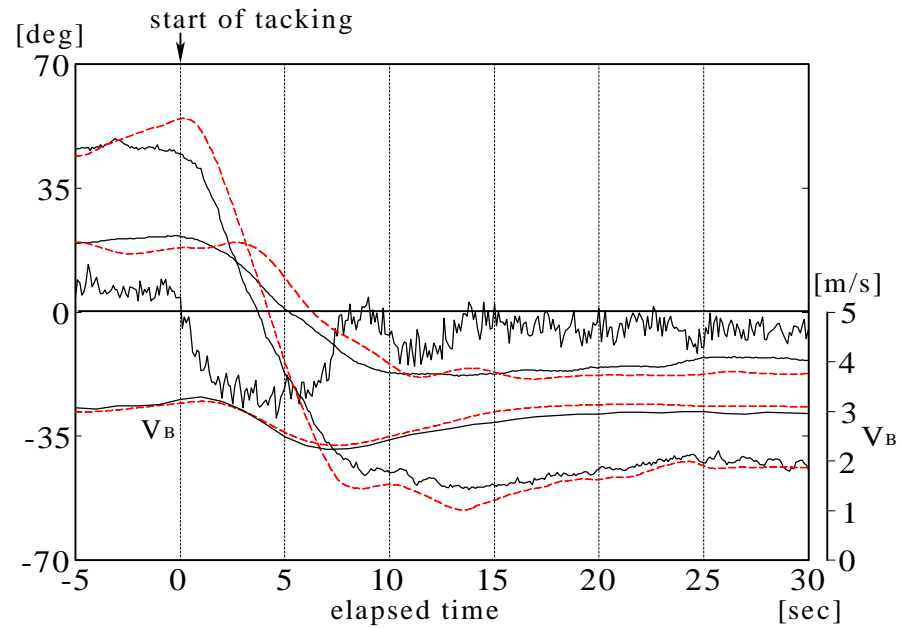
(a) Trajectory of boat



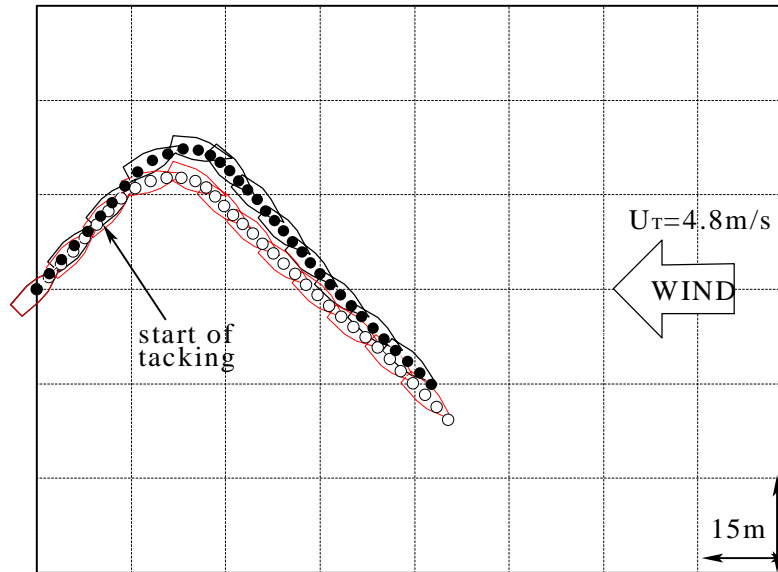
(b) Boat attitude parameters



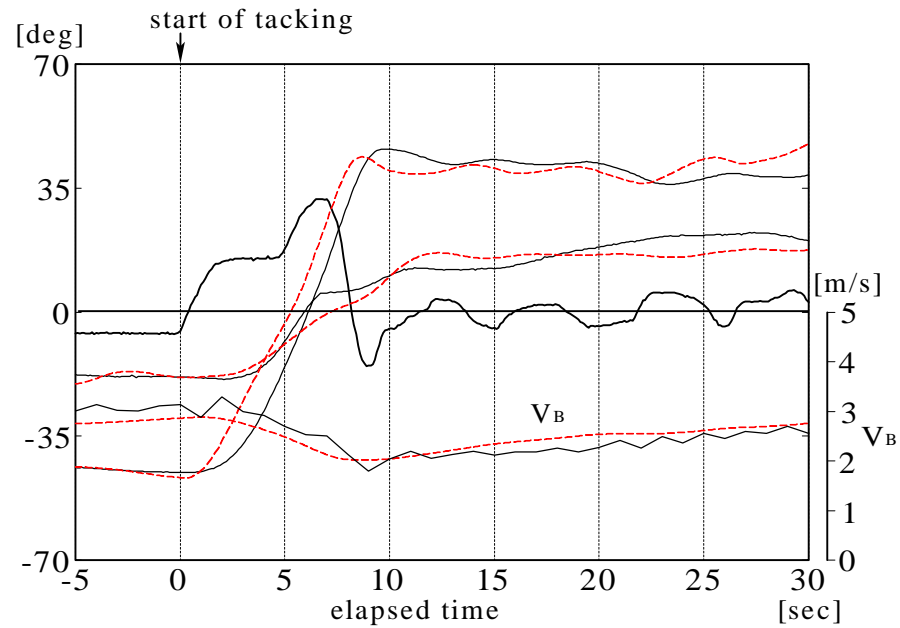
(a) Trajectory of boat



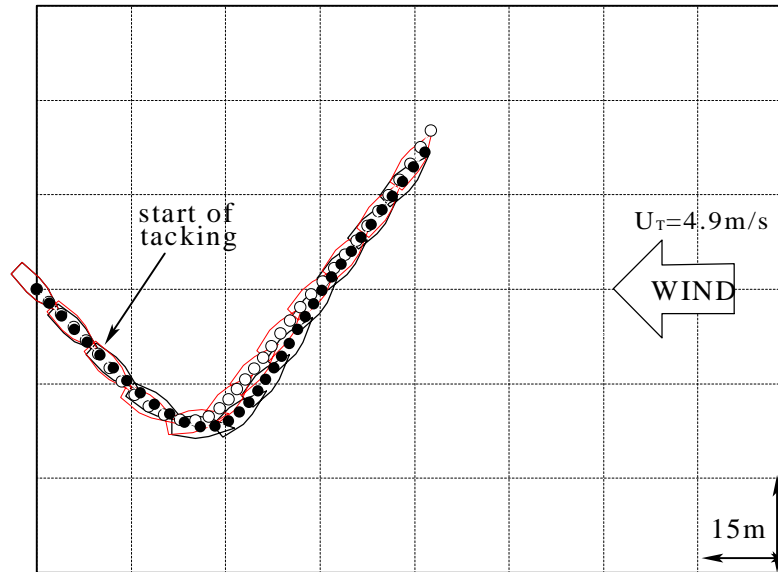
(b) Boat attitude parameters



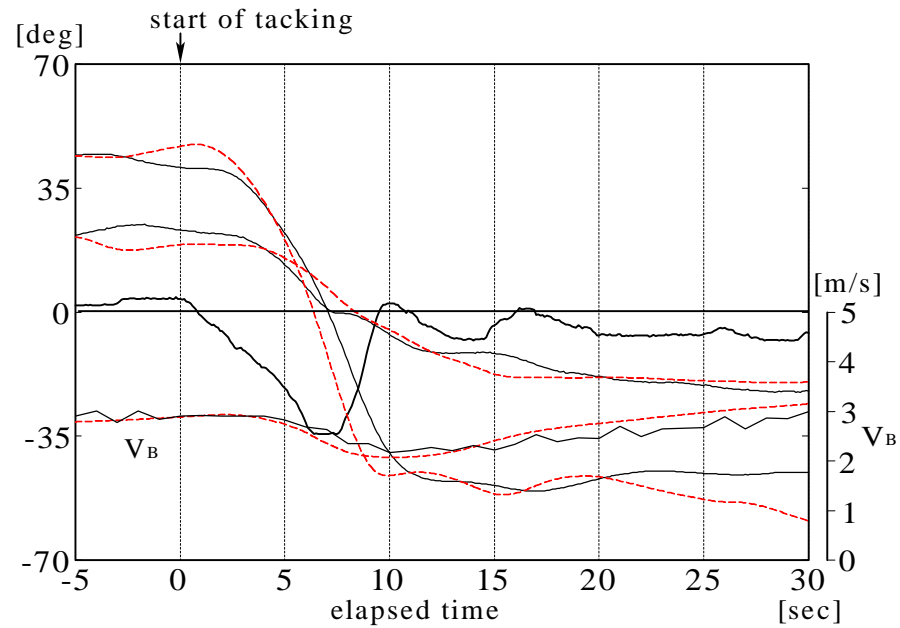
(a) Trajectory of boat



(b) Boat attitude parameters



(a) Trajectory of boat



(b) Boat attitude parameters

*Thank you
for your kind attention.*