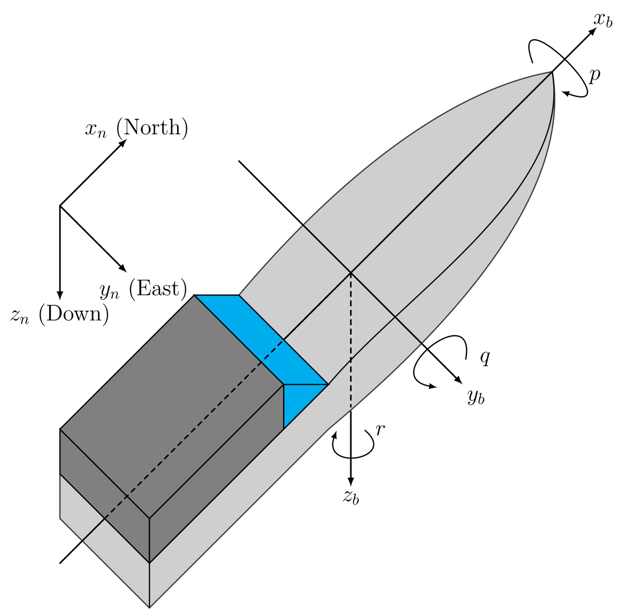
Modelling of Environmental Disturbances for Ships

Fredrik Ljungberg and Martin Enqvist

Introduction

Marine modelling is a rather involved task due to the non-linear dynamic forces and moments affecting the vessel. The forces and moments are primarily caused by interaction with the surrounding water but in the case of surface vessels, also by interaction with the surrounding air. This is especially true for vessels that expose a large side area to the wind, like container ships and cruise ferries. Generally, the two surrounding media will move with respect to each other which gives rise to system disturbances. In this work, two ideas for including environmental disturbances in ship models are presented.

Undisturbed equations of motion



The equations of motion under undisturbed conditions:

$$\dot{\eta} = J(\eta)\nu, \tag{1a}$$

$$M\dot{\nu} + C(\nu)\nu + D(\nu)\nu + g(\eta) = \tau_{\text{act}}. \tag{1b}$$

η	Global position and attitude.
ν	Translational and angular velocities.
τ_{act}	Forces and moments caused by actuators.
$J(\eta)$	Attitude dependent rotation matrix.
M	Mass and inertia elements.
$C(\nu)$	Coriolis and centripetal forces.
$D(\nu)$	Energy losses due to damping.
$g(\eta)$	Static forces (buoyancy and gravity).

Velocity of ocean current as disturbance

1. Divide M and $C(\nu)$ into separate parts for rigid-body kinetics and hydrodynamics

$$M = M_{RB} + M_A,$$
$$C(\nu) = C_{RB}(\nu) + C_A(\nu).$$

2. Realize that rigid-body effects depend on the absolute velocity

$$\tau_{RB} = M_{RB}\dot{\nu} + C_{RB}(\nu)\nu,$$

and hydrodynamic forces depend on the relative velocity

$$\tau_{\text{hyd}} = M_A\dot{\nu}_r + C_A(\nu_r)\nu_r + D(\nu_r)\nu_r.$$

ν_c	Velocity of surrounding water.
$\nu_r = \nu - \nu_c$	Relative velocity between ship and water.

3. Write (1b) as

$$M_{RB}\dot{\nu} + M_A\dot{\nu}_r + C_{RB}(\nu)\nu + C_A(\nu_r)\nu_r + D(\nu_r)\nu_r + g(\eta) = \tau_{\text{act}}.$$

and treat ν_c as a disturbance.

Wind force as disturbance (common)

Assume the principles of superposition

$$M_{RB}\dot{\nu} + M_A\dot{\nu}_r + C_{RB}(\nu)\nu + C_A(\nu_r)\nu_r + D(\nu_r)\nu_r + g(\eta) = \tau_{\text{act}} + \boxed{\tau_{\text{wind}}}, \tag{2}$$

and treat $\tau_{\text{wind}} \neq \tau_{\text{wind}}(\nu)$ as a disturbance.

Wind velocity as disturbance (proposed)

1. Introduce an aerodynamic damping matrix

$$\tau_{\text{air}} = F(\nu_q)\nu_q.$$

ν_w	Velocity of surrounding air.
$\nu_q = \nu - \nu_w$	Relative velocity between ship and air.

2. Write (1b) as

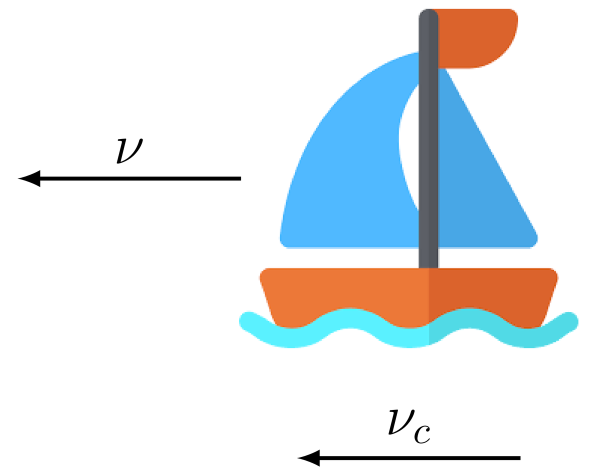
$$M_{RB}\dot{\nu} + M_A\dot{\nu}_r + C_{RB}(\nu)\nu + C_A(\nu_r)\nu_r + D(\nu_r)\nu_r + g(\eta) + \boxed{F(\nu_q)\nu_q} = \tau_{\text{act}}, \tag{3}$$

and treat ν_w as a disturbance.

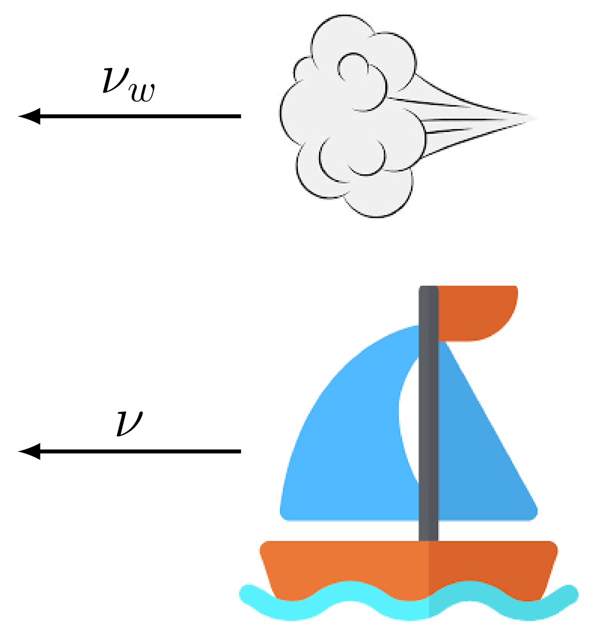
Pros and cons

- Treating the wind force as a disturbance makes it possible to separate the wind model from the system dynamics.
- Identifying $F(\nu_q)$ provides further information about the ship.
- Adopting the superposition principle surrenders physical rationality. For example:

1. If the ship drifts with the current, $\nu_r = 0$, during a windless day, $\tau_{\text{wind}} = 0$, model (2) gives no aerodynamic damping.



2. If the ship drifts with the wind, $\nu_q = 0$, during a windy day, $\tau_{\text{wind}} \neq 0$, the model (2) gives aerodynamic damping even when there is none.



Summary

Modelling as in (2) works well in some cases but gives non-physical behavior. Moreover, estimating the extra parameters in (3) gives additional information about the system.

Included in lic thesis: Estimators for models like (3), which are consistent under assumptions that the wind and the current have got deterministic parts which do not change during the experiment and stochastic parts which have zero mean.

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