Description of Ship Maneuvering Data Collected from K-SIM Simulator

Beatriz Sanguino

May 2024

Norwegian University of Science and Technology

Faculty of Engineering

Department of Ocean Operations and Civil Engineering

Introduction

This document supports the data files annexed to it, explaining the data contained within those files. All data files provided in the different folders follow the format represented in Figure 1.

Time	Surge Speed	Sway Speed	Yaw Rate	Heading	x	y	Rudder Angle	Wind Direction	Wind Speed
0	5.41043672	8.22E-14	-1.67E-15	-6.46E-13	842.2507	-1.76E-07	0	3.141592654	0
0.1	5.41043689	-3.34E-12	2.63E-14	-6.46E-13	842.7917	-1.77E-07	0	3.141592654	0
0.2	5.4104372	-4.80E-13	2.39E-14	-6.46E-13	843.3328	-1.77E-07	0	3.141592654	0
0.3	5.41043768	-7.92E-13	6.62E-15	-6.46E-13	843.8738	-1.77E-07	0	3.141592654	0
0.4	5.41043776	-4.14E-13	-7.01E-14	-6.46E-13	844.4149	-1.77E-07	0	3.141592654	0
0.5	5.41043815	1.91E-12	-4.27E-14	-6.46E-13	844.9559	-1.77E-07	0	3.141592654	0

Figure 1 – Example of the content of the data files.

The purpose of this document is to provide a description of each variable to facilitate a better understanding of the data. The data files contain information collected from the K-sim simulator for a Ro-Ro ferry performing various maneuvers under different wind conditions.

Degrees of Freedom (DoF) in Marine Vessels

During maneuvering, a marine vessel experiences motion across six degrees of freedom, including translational motion along the x, y, and z axes, as well as rotational motion around those axes. In the maritime domain these motions are referred to as surge, sway, heave, roll, pitch, and yaw, as illustrated in Figure 2. When focusing on the ship maneuver in the horizontal plane it is common to only consider 3 DoF (surge, sway and yaw motions).

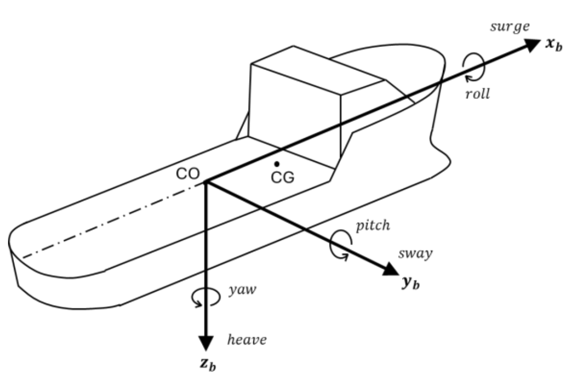
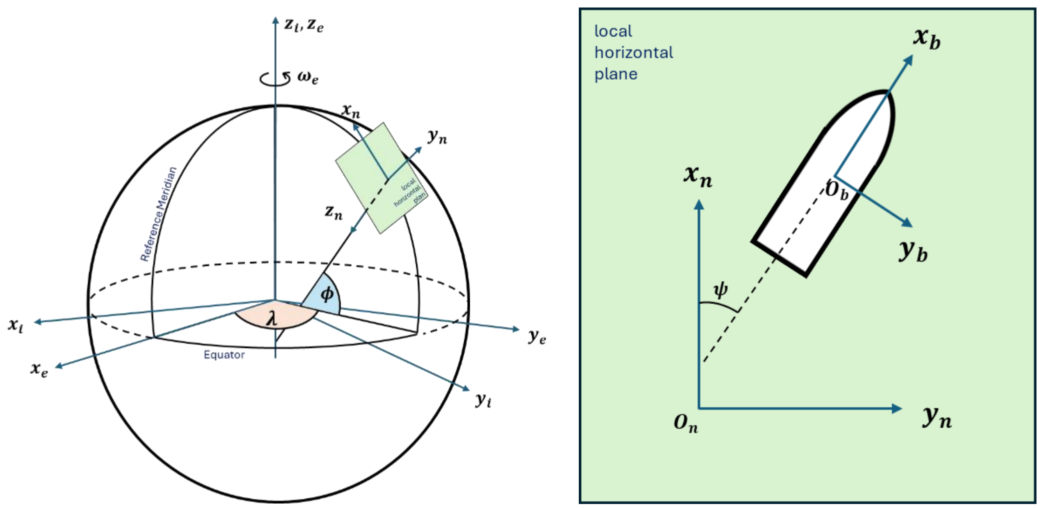


Figure 2 – Six degrees of freedom of a vessel (figure based on (Fossen, 2011)).

Coordinate Reference Systems

When discussing variables and degrees of freedom, it is important to specify the reference system used to measure these quantities.



a) b)

Figure 3 – ECI, ECEF, NED and body-fixed reference frames (figure based on (Fossen, 2011) and (Sanguino, 2023)).

There are several reference systems that are commonly used when discussing ship maneuvering motion, as shown in figure 3:

- Earth-Centered Inertial (ECI) frame $\{i\} = (x_i, y_i, z_i)$: inertial frame with its origin fixed in the center of the Earth.
- Earth-Centered Earth-Fixed (ECEF) reference frame $\{e\} = (x_e, y_e, z_e)$: its origin is also fixed in the center of the Earth, but its axes rotate with the Earth. For marine vessels, Earth's rotation can often be disregarded, so this frame can be considered an inertial reference frame. As illustrated in Figure 3 a), the x-axis is aligned with the intersection of the Prime Meridian and the Equator, the z-axis points towards the True North Pole, and the y-axis completes the right-handed cartesian coordinate system by pointing eastward along the Equator.
- North-East-Down (NED) reference system $\{n\} = (x_n, y_n, z_n)$: local coordinate system defined relative to the Earth's reference ellipsoid model (WGS 84). As shown in Figure 3 a), its origin is fixed to a point on the Earth's surface, with the x-axis oriented towards the True North, the y-axis toward East, and the z-axis downward along the ellipsoid normal. The location of this frame $\{n\}$ relative to ECEF frame $\{e\}$ is determined using geodetic coordinates (latitude ϕ, longitude λ, and altitude h).

For marine operations in the proximity of the origin of the frame $\{n\}$, the tangent plane is normally used for navigation (called flat Earth navigation), and this frame can be considered an inertial reference frame.

- Body-fixed reference frame $\{b\} = (x_b, y_b, z_b)$: moving reference frame fixed to the vessel. Usually, the origin of this reference system is selected at a point midships on the waterline (point CO in Figure 2). Its axes are typically aligned with the principal axes of inertia, with the x-axis oriented longitudinally along the ship, the y-axis transversely, and the z-axis normal to the rotation axis (from top to bottom). Figure 3 b) shows the x and y-axis of this frame and its relationship with the frame $\{n\}$.

Data Description

Considering the information above, the variables on the data files corresponds to:

- Time [in seconds]: Time of the maneuver (the sampling frequency of the data is 1 Hz).
- Surge Speed and Sway Speed [in m/s]: Speed of the origin of the body frame (O_b) with respect to the $\{n\}$ frame, expressed in frame $\{b\}$.
- Yaw Rate [in rad/s]: Angular velocity of $\{b\}$ with respect to $\{n\}$.
- Heading [in rad]: Angle between x_b and x_n, measured from -π to π.
- x and y [in meters]: Position of O_b relative to $\{n\}$, expressed in $\{n\}$.
- Rudder Angle [in rad]: Angle of the azimuth thrusters of the vessel, measured from -π to π. This variable is controlled to perform the ship maneuvers (the RPMs can also be controlled, but for the data provided they were kept constant at 80% of the maximum RPMs which corresponds to 206 RPM).
- Wind Direction [in rad]: Direction of the wind measured as shown in figure 4, where V_w is the wind vector, and β_w is the wind direction angle.
- Wind Speed [in m/s].

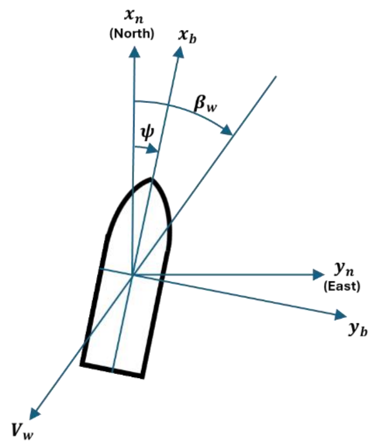


Figure 4 – Representation of the wind vector (figure based on (Fossen, 2011)).

In addition to the variables presented in Figure 1 and collected in the provided files, more variables can be obtained from the K-sim simulator if needed, such as roll, pitch, heave motion, and others. Additionally, the maximum sampling frequency provided by the simulator is 10 Hz.

It is important to note that, to obtain the data as presented in Figure 1, the raw data collected from the simulator needs to be processed to be in accordance with the reference systems and units presented above. For this a python script was used to perform these conversions.

Vessel Details

The vessel used for collecting the data is a Ro-Ro ferry (BastÃ Fosen), with the main characteristics presented in Figure 5. This vessel is equipped with two azimuth thrusters, one at the fore and one at the stern. In the data collected, both thrusters are controlled synchronously, so that the angle of the thrusters is always the same. Even though the vessel does not have any rudders, this nomenclature is used to refer to the angle of the azimuth thruster.

Variable	Description	Value	Units
L_{pp}	Length between perpendicular	137.2	m
L_{OA}	Length overall	142.9	m
B_{mld}	Beam moulded	21	m
T_a	Draught aft	4.5	m
T_{fwd}	Draught fore	4.5	m
M	Displacement	4726	ton
C_b	Block coefficient	0.36	
k_z	Radius of inertia	0.26	multiples of L_{pp}
A_{L_w}	Lateral windage area	1400	m^2

Figure 5 – Characteristics of the Ro-Ro ferry (BastÃ Fosen).

Maneuvers Collected

Each file provided in each folder corresponds to a specific maneuver performed by the vessel. The dataset includes three types of maneuvers: zigzag, turning, and random.

In the turning maneuver the rudder angle is set to a specific angle and is maintained constant for the rest of the maneuver. In the data set provided, turning 10 and turning 20 maneuvers were performed, setting the rudder angles to 10 and 20 degrees respectively.

In the zigzag maneuver, the vessel alternates its rudder by δ degrees to either side when the ship deviates ψ degrees from the initial course, as shown in Figure 6. Initially the rudder is moved to starboard by δ degrees (first execute), and once the vessel's heading deviates ψ degrees from the initial course, the rudder is reversed to the same angle but portside (second execute). Following the counter rudder application, the vessel initially continues yawing in its original direction (clockwise) with a decreasing yaw rate until it changes direction, eventually yawing counterclockwise. When the vessel's heading deviates ψ degrees off course again, the rudder is again reversed to δ degrees starboard (third execute), and this cycle repeats. This maneuver is characterized by the combination of the values of heading ψ and rudder angle, denoted as δ/ψ. In the data set provided the zigzag maneuvers performed are the zigzag 10/10 (denoted as "zigzag10" in the file name), the zigzag 15/15 (denoted as "zigzag15" in the file name), the zigzag 20/20 (denoted as "zigzag20" in the file name) and the zigzag 30/30 (denoted as "zigzag30" in the file name).

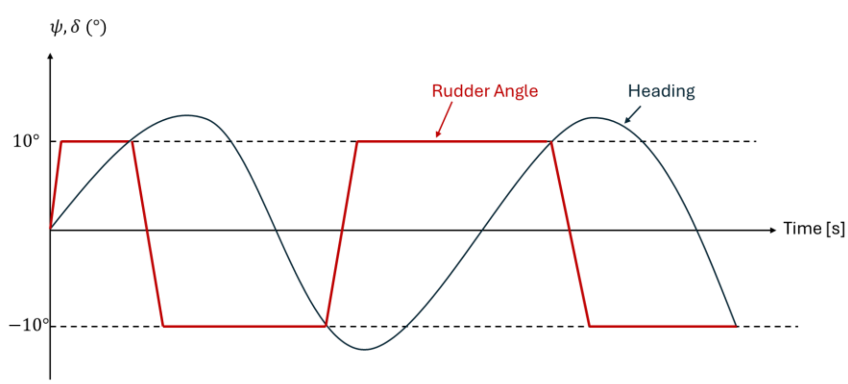


Figure 6 – Zigzag Maneuver.

In the random maneuver, changes in the rudder angle occur at specified time intervals. In the data set provided three random maneuvers are performed (the "random1", the "randomLow", and the "randomHigh"), with their rudder variation over time shown in figure 7 to 9.

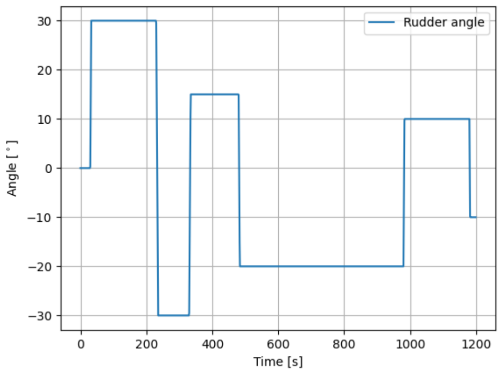


Figure 7 – “random1” Maneuver.

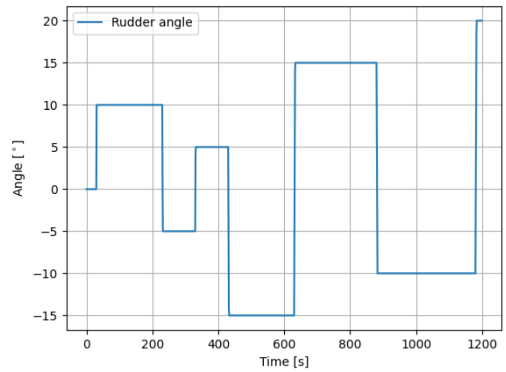


Figure 8 – “randomLow” Maneuver.

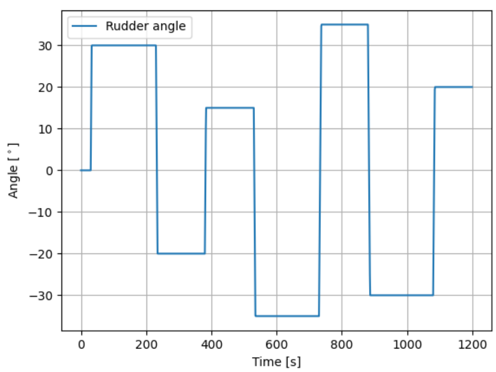


Figure 9 – “randomHigh” Maneuver.

Files and Folders Organization

The data provided is organized in different folders depending on the wind conditions they were collected under: “2knots”, “7knots”, “12knots”, “17knots”, “No_Wind”.

Each folder contains a file per maneuver performed, and the file names have the following format: “{manuever type}_initHeadind{initial heading of the vessel}_{wind condition}”, where the wind condition is “No_Wind” or “{wind speed}knots_wind{wind direction in degrees}d”.

References

Fossen, T. I. (2011). *Handbook of Marine Craft Hydrodynamics and Motion.* John Wiley Sons, Ltd.

Sanguino, J. (2023). *Lecture notes on Navigation Systems*. IST Universidade de Lisboa.