# MOTIONS AND CONTROL OF MARINE VEHICLES

# DEN462E

# TERM PROJECT

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https://colab.research.google.com/drive/1HUDmpYKACYiA6_mjgKyVANLBURMRPNuz?usp=sharing

**The codes for this assignment are in colab!**

# Given Data

| s1 | s2 | s3 | s4 | s5 | s6 |
|---|---|---|---|---|---|
| m | knots | L | deg | % | deg/s |
| 115 | 14 | 3.25 | 35 | 40 | 0.5 |

| Parameters | Abbreviations | Given Values | Units |
|---|---|---|---|
| Length | L | 115 | m |
| Speed fwd. | U | 7.2016 | m/s |
| Speed Loss | | 40% | - |
| Steady Speed | U_std | 3.24072 | m/s |
| Steady Turning Diameter | STD | 3.25 | L |
| Steady Turning Diameter | Dtc | 373.75 | m |
| Steady Turning Radius | Rtc | 186.875 | m |
| Rudder Angle | $\delta$ | 35 | deg |

# Questions

Consider a ship with length $L = s_1$ moving with a forward speed of $U = s_2$. The turning circle tests revealed that this ship achieves a steady turning diameter of $STD = s_3$ at a rudder angle of $\delta = s_4$, and loses $s_5$ of its speed during this turning.

## Question a-)

a. Write down the equation relating the yaw rate to the ship's rudder angle.

## a anwser-)

| | | | |
|---|---|---|---|
| Yaw Rate | $r = \left(\frac{U\_std}{Rtc}\right)$ | 0.0173416 | rad/s |
| Yaw Rate | r | 0.994 | deg/s |

The term "yaw rate" describes the rotational speed or angle of an item or vehicle about its vertical axis. The yaw rate in the context of a ship is the speed at which the ship is rotating or turning around its vertical axis.

Question b-)

b. Calculate the K-index of the ship.

b answer-)

| | | | |
|---|---|---|---|
| K_index | $K_{index} = r/\boldsymbol{\delta}$ | 0.0283892 | 1/s |

The K-index of the ship is a dimensionless value that represents the ship's maneuverability.

Question c-)

After the turning circle tests, the ship was subjected to a course-keeping test and it was found that the ship is turning at a residual yaw rate of $r_b = s_6$, even at the neutral rudder angle of $\delta = 0°$.

c. Modify the equation in (a) using the residual yaw rate.

c answer-)

Residual Yaw Rate is given as 0.5 deg/s

δ is given as 0 degrees

Yaw Rate (r) = (k*δ)+rb

Yaw Rate (r) = (0.0283*0)+0.5

Yaw Rate = 0.5 deg/s

Question d-)

You will be developing the time-based course-keeping simulation of this ship for . Take the following as the initial condition of your ship:

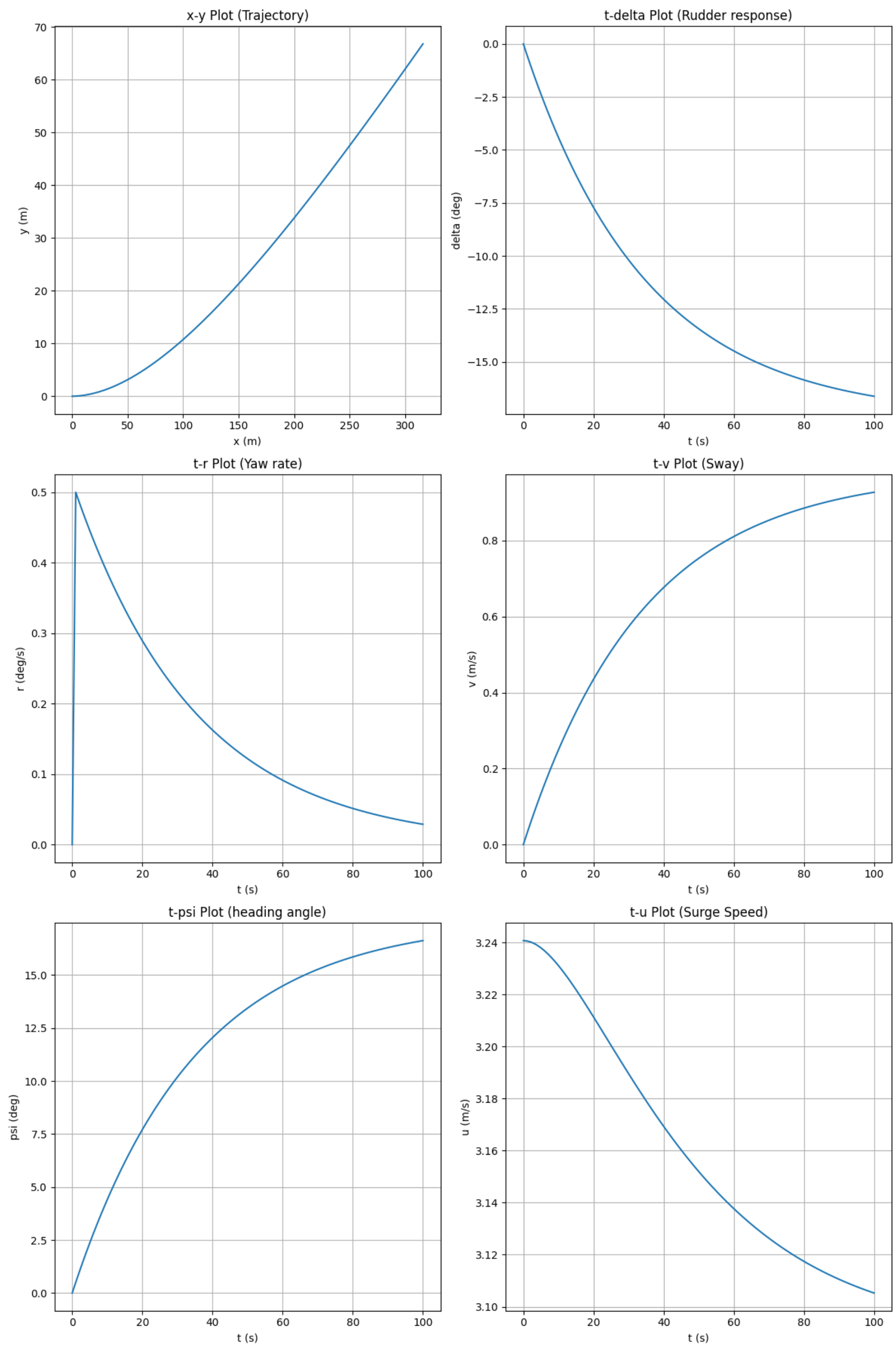
$$\psi_0 = \delta_0 = v_0 = x_0 = y_0 = 0$$

Here; $\psi$ is the ship's heading angle, $v$ is the ship's sway speed, $x$ and $y$ are the ship's position in x- and y-axes, respectively.

d. Use a proportional controller to keep the ship at a target heading angle of $\psi_t = 0°$. Take $K_P = 1$. Graph the yaw rate, heading angle, rudder angle, surge speed, and sway speed in time. Plot the ship's trajectory.

d answer-)

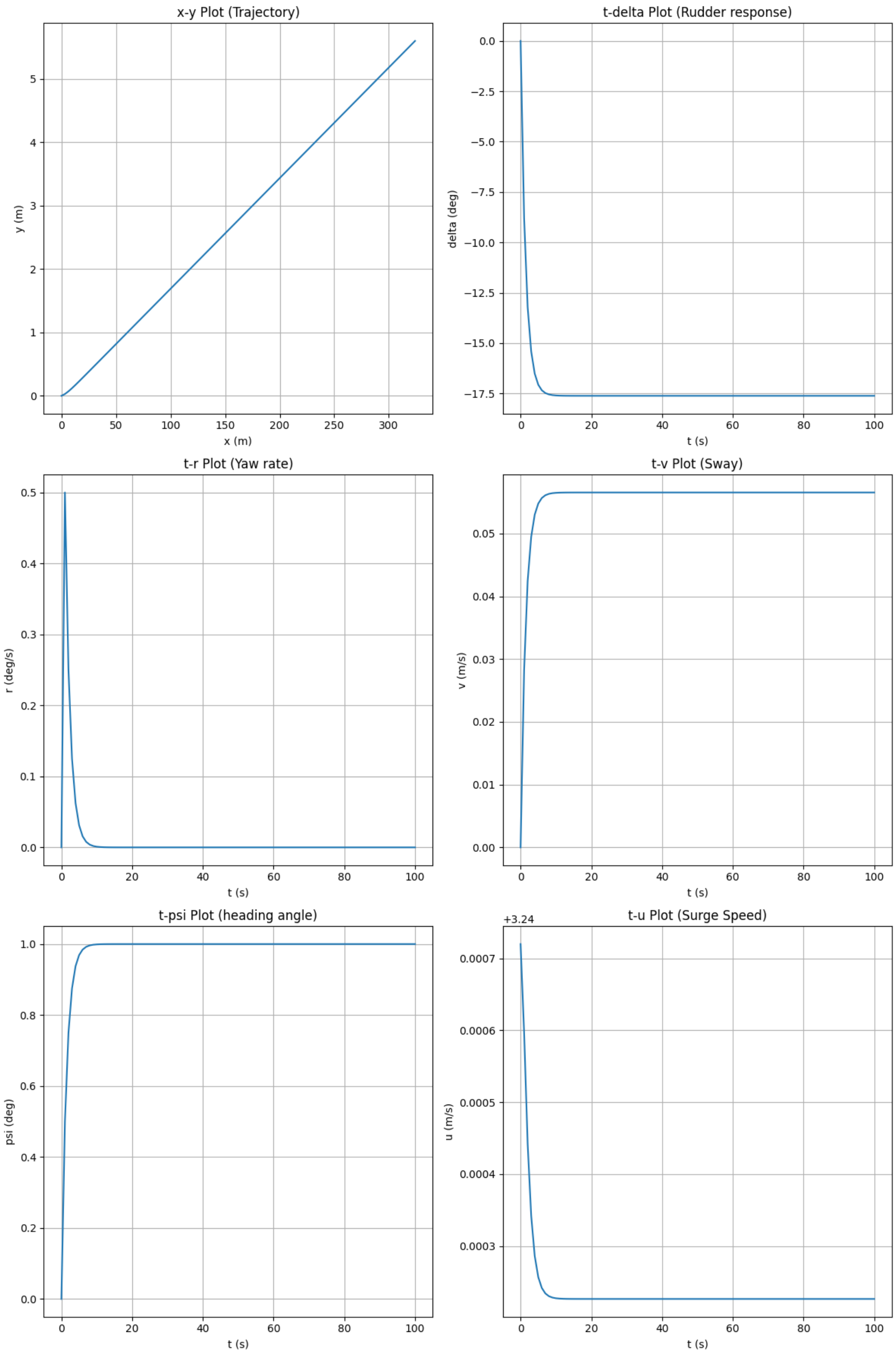
Kp refers to the proportional gain of the proportional controller used to maintain the ship at a target heading angle.




## Question e-)

e. Do the same using $K_p = 1/(2K)$.

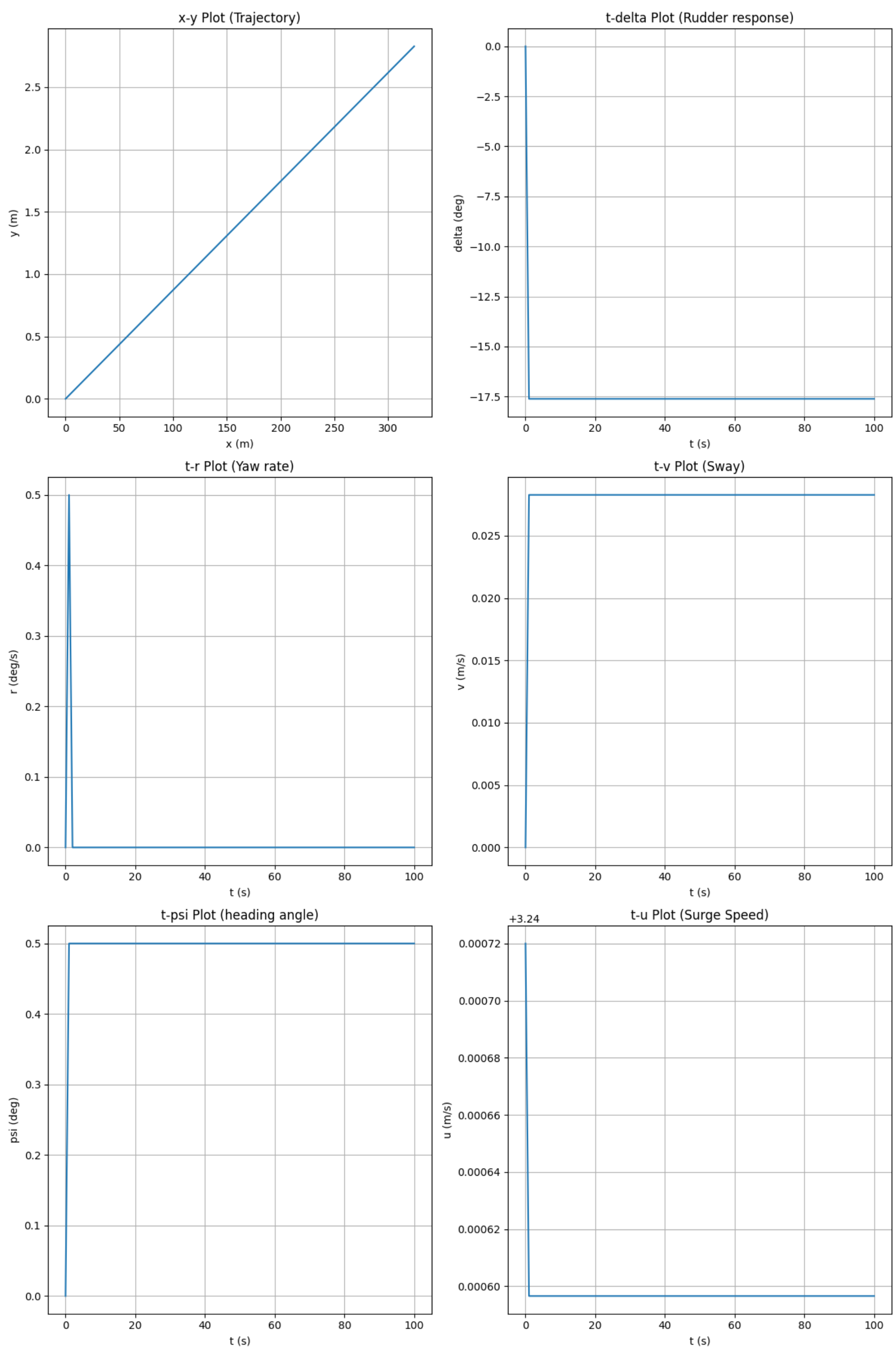
e answer-)


x-y Plot (Trajectory)
y (m)
x (m)
t-delta Plot (Rudder response)
delta (deg)
t (s)
t-r Plot (Yaw rate)
r (deg/s)
t (s)
t-v Plot (Sway)
v (m/s)
t (s)
t-psi Plot (heading angle)
psi (deg)
t (s)
+3.24
t-u Plot (Surge Speed)
u (m/s)
t (s)

## Question f-)

f. Do the same using $K_P = 1/K$. Write down the notable differences observed in the responses of both the ship and rudder.

## f answer-)



When we adjust the proportional gain (KP) for the rudder control system by setting it to 1 divided by K, some interesting differences can be observed in how both the ship and the rudder respond.

When KP is increased, the rudder response becomes more sensitive to changes in the heading angle error. This means that even small variations in the heading angle error will have a greater impact on the rudder control input (delta). Consequently, the rudder will make larger adjustments to minimize the heading angle error, leading to more aggressive steering actions.

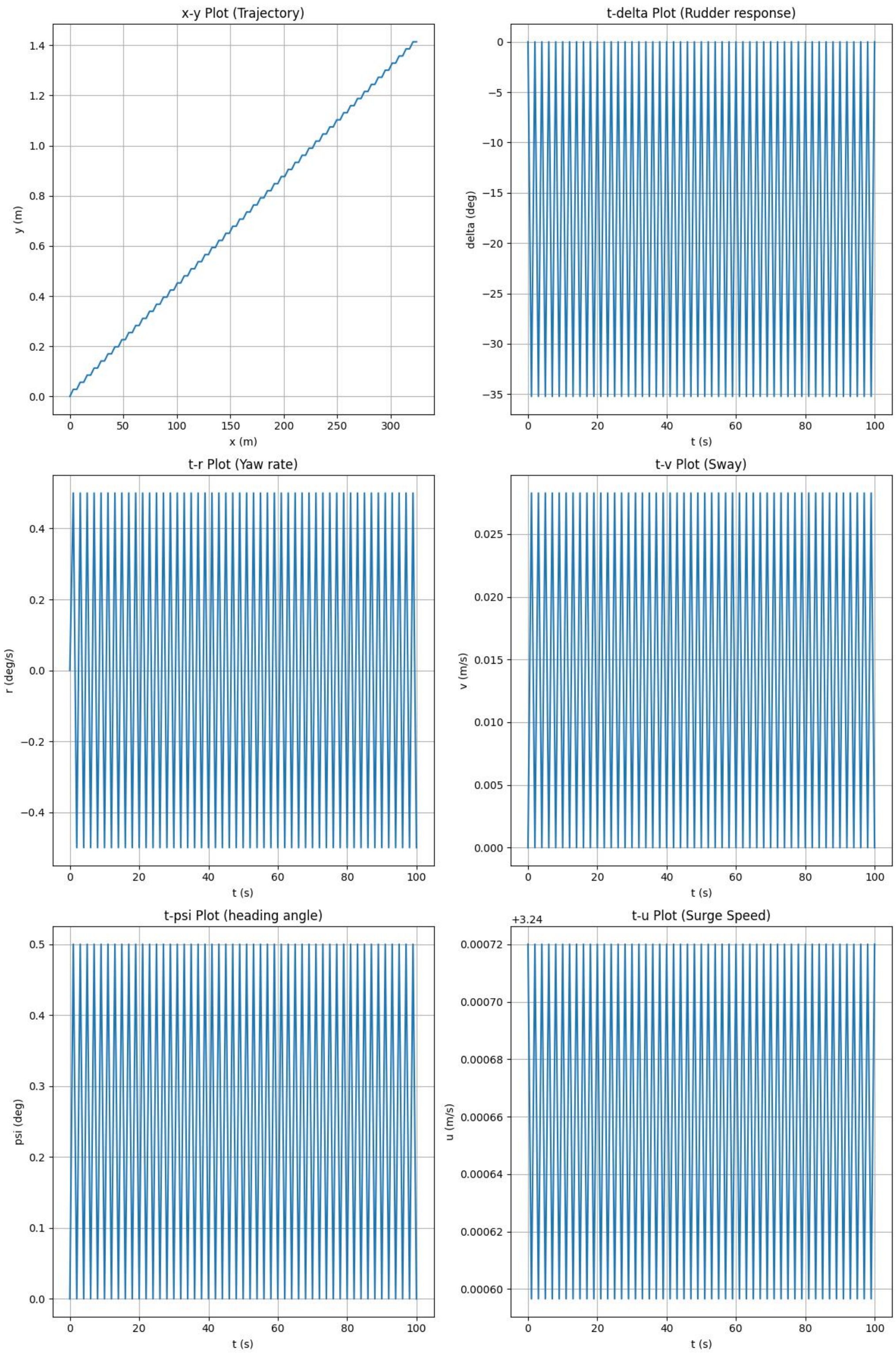
This increased sensitivity also affects the ship's yaw rate (r), causing it to change faster and with more intensity. As the rudder response becomes more sensitive, the ship's yaw rate will accelerate more rapidly in order to correct the heading angle error. Moreover, the ship's heading angle (psi) will converge towards the desired heading angle more quickly when using a higher KP value. The larger adjustments made by the rudder control system enable the ship's heading angle to reach the target more swiftly. However, it's important to note that the impact on the ship's surge speed (u) and sway speed (v) may vary depending on the specific dynamics of the ship and the surrounding environment. Changes in the rudder control can influence the ship's trajectory and speed.

Nevertheless, it is crucial to find a balance when determining the appropriate KP value to prevent excessive control. Employing too much control can lead to instability or oscillations in the system, which is undesirable.

Question g-)

g. Do the same using $K_P = 2/K$. Please provide an explanation of what happens in this condition and state the reasoning behind it.

g answer-)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t-psi Plot (heading angle)
psi (deg)
t (s)
t-u Plot (Surge Speed)
+3.24
u (m/s)
t (s)

The value of KP determines how strongly the rudder angle is adjusted based on the difference between the desired heading angle and the actual heading angle. When we set KP = 2/K, it means that the rudder angle correction is influenced by the heading angle error divided by the system gain.

Here's what happens:

- If the system gain is high, indicating a strong response of the vessel's yaw rate, the rudder angle correction will be smaller for a given heading angle error. The system is less sensitive to small errors, so it makes smaller adjustments to the rudder angle.
- Conversely, if the system gain is low, meaning the vessel's yaw rate response is weaker, the rudder angle correction will be larger for the same heading angle error. The system is more sensitive to errors, so it makes bigger adjustments to the rudder angle.

Setting KP = 2/K affects how aggressively the vessel corrects its heading angle. A higher KP value (for a lower K value) means the vessel responds more quickly and forcefully to heading angle errors by making larger rudder angle adjustments. On the other hand, a lower KP value (for a higher K value) results in a less aggressive response, with smaller adjustments to the rudder angle.

The reason behind this adjustment is to find the right balance between response speed and stability. A higher KP value can provide a faster response when immediate adjustments are needed, but it can also lead to overshooting or instability. A lower KP value prioritizes stability and smoother response, requiring larger errors to trigger significant rudder angle corrections.

Consider the vessel's characteristics and the desired control behavior when choosing KP. Careful tuning is necessary to find the right balance that suits the vessel's dynamics and stability requirements.