Mathematical Ship Model No. 3789

Copenhagen

FORCE 115-20336 / 2016-08-29

Title of report and Project No.:

Ship Description

Ship 3789

Ferry

Service Condition

Copenhagen

Client:		***Ref.:***	115-20336		
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Ship characteristics
Equilibrium speeds

Classification:

Open
Internal
X Confidential

List of Contents

Nomenclature and Definitions

LCB	Longitudinal centre of buoyancy
L_{pp}	Length between perpendiculars
R	Radius of propeller
T	Draught

The ship is defined in a right hand coordinate system with x positive forward and y positive to starboard. The path of the ship is referred to the origin of the ship, i.e. at the intersection between amidships and the centreline. Rudder angles are defined positive to port.
Wind direction : Wind coming from [angle]
Wave direction: Waves going to [angle]
Current direction: Current going to [angle]

1 Ship Description

The ship is a 169.5 m long and 24.8 m wide ferry in a service condition. It is propelled by a single controllable pitch propeller mounted in the centreline and two azimuth thrusters equipped with fixed pitch propellers. The service speed at the design draught is 24.9 knots. The vessel is fitted with one spade rudder in the CL and has two bow thrusters.

In the following sections the word “rudder angle” will be also used for the azimuth thruster angle.

2 Basis for Mathematical Ship Model

The mathematical model of the ship were based on results from tests in the shallow water basin at HSVA with a scaled (1:16.983) model of the ferry. The updated version is set to match the sea trials of the sister ship “M/V Berlin”. The seakeeping properties of the ship and shallow water effect on the hull forces have been scaled from a similar model to fit the conditions of the present ship. Wind load data has been obtained from wind tunnel test measurements of a similar ship.

The basis for the mathematical ship model is summarized in Table 2-1.

Effect (device)	Scaled from similar model	Predicted using database tool (ShipYard)	Specific model tests (PMM / wind tunnel)	Specific calculations (CFD / OMEGA)	Full scale trial data
Hull hydrodynamics					X
Shallow water effects			X		X
Propulsion & rudder			X		
Thrusters					
Wave loads	X				
Wind loads	X				
Bank effects	X				
Ship-ship interaction	X				
Hydrostatic forces	X				
Engine characteristic	X				
Anchor characteristic	X				

Table 2-1: Basis for Mathematical Ship Model

3 Manoeuvring Characteristics

The manoeuvring characteristics of the vessel are governed by two azimuth thrusters and one centre propeller configuration, giving better stopping capability than a conventional vessel of similar dimensions. The ship is course stable as it can be seen from the spiral curve. Its turning ability as seen from the turning circle test is good. The stopping ability of the ship is excellent and well below the IMO recommendations of 15 ship lengths. The ship is seaworthy with a maximum roll angle of around 6.0 deg in 3 m waves (significant wave height). When sailing in cross winds of 15 m/s the steady heel angle is about 0.6 deg. The autopilot is not fully stable after the latest tuning.

The main manoeuvring characteristics of the ship model are listed in Table 3-1.

Parameter	Ferry	IMO limit
Turning circle, Advance	3.1 · L_{pp}	4.5 · L_{pp}
Turning circle, Tactical diameter	2.8 · L_{pp}	5.0 · L_{pp}
10/10 zig-zag, 1st overshoot angle	12.7 deg	11.1 deg
10/10 zig-zag, 2nd overshoot angle	23.3 deg	26.7 deg
20/20 zig-zag, 1st overshoot angle	26.3 deg	25.0 deg
Crash stop, Track reach	5.7 · L_{pp}	15 · L_{pp}
Azimuth Crash stop, Track reach	3.7 · L_{pp}	-

Table 3-1: Manoeuvring Characteristics

Note the manoeuvres have the initial speed of 19.5 knots to match the sea trial. Note the standard crash stop has been performed by using the fixed propeller, while the azimuth stop has been performed by turning the pods outward to ±180 deg.
Track plots and time series from simulated standard manoeuvres are given in Appendix A.

4 Ship Particulars

Type of ship Condition Ship No.		Ferry Service 3789
Length between Perpendiculars	m	156.45
Length overall	m	169.5
Breadth moulded	m	24.8
Depth moulded	m	14.25
Draught fore/aft	m	5.46/5.46
Displacement	m^3	12364
Wetted Surface	m^2	4057
Frontal wind Area	m^2	500
Lateral wind Area	m^2	3160
Block Coefficient based on Lpp	-	0.584
Trim by the Stern	%	0
Metacentric Height	m	2.43
LCB, % of LPP forw. of LPP/2	%	-3.97
Radius of Inertia, % of LPP	%	25.0
Type of Engine		Diesel
Number of Propellers		3
Type of Propellers		Center – CP Azimuth thrusters - FP
Direction of Rotation		Center – Counter Clockwise Azimuth thrusters -
Number of Blades		Outwards
Propeller Diameter	m	5 Center - 4.6
Pitch Ratio at 0.7R		Azimuth thrusters – 3.0 Center - 1.20
Area Ratio		Azimuth thrusters – 1.03 Center - 0.766
Shaft Power (ahead) total	kW	Azimuth thrusters – 0.719 1 X 13500 2 X 3500
Number of Rudders		3
Type of Rudders		Center Rudder - Spade 2x Azimuth thrusters
Position off CL	m	Center rudder - 0 Azimuth thrusters - +/- 7.69
Area of Rudder	m^2	Center rudder - 11.0
Total rudder Area/LBP x T	%	1.29
Turning Velocity of Rudder (two Pumps)	deg/s	Center rudder - 4.6 Azimuth thrusters - 9.0

Max. rudder Angle	deg	Center rudder 35 Azimuth Thrusters +/-180
Anchor Weight	kg	4836
Chain Weight	kg/m	100.0
Number of bow Thrusters		2
Nominal bow thruster Power	kW	2 X 1350
Number of stern Thrusters		0

Table 4-1: Ship Particulars

5 Equilibrium Speeds

Ship Engine Setting	Centre Propeller		Azimuth Thrusters		Speed, knots	
	RPM	Pitch	RPM	Pitch	1000 m	6.6 m
1.0	164	1.2	254	1.02	24.9	12.8
0.8	149	0.9	203	"	18.8	12.3
0.5	121	0.5	127	"	10.6	8.4
0.25	98	0.3	64	"	4.7	4.0
0.125	98	0.2	32	"	3.0	2.6
-0.125	98	-0.2	32	"	-1.5	-0.9
-0.25	98	-0.4	64	"	-4.5	-3.6
-0.5	121	-0.6	127	"	-9.5	-7.7
-1.0	164	-0.8	254	"	-17.0	-11.3

Table 5-1: Propeller RPM and pitch, and equilibrium speeds for various handle settings for two water depths: deep water and shallow water corresponding to 1.2 times the mean draught.

6 Azimuth units range

The azimuth units have been limited to avoid the flow wash the hull. The limitation is set up in a range between 60º to 150º towards the hull (positive values for the starboard unit and negative for the port one).

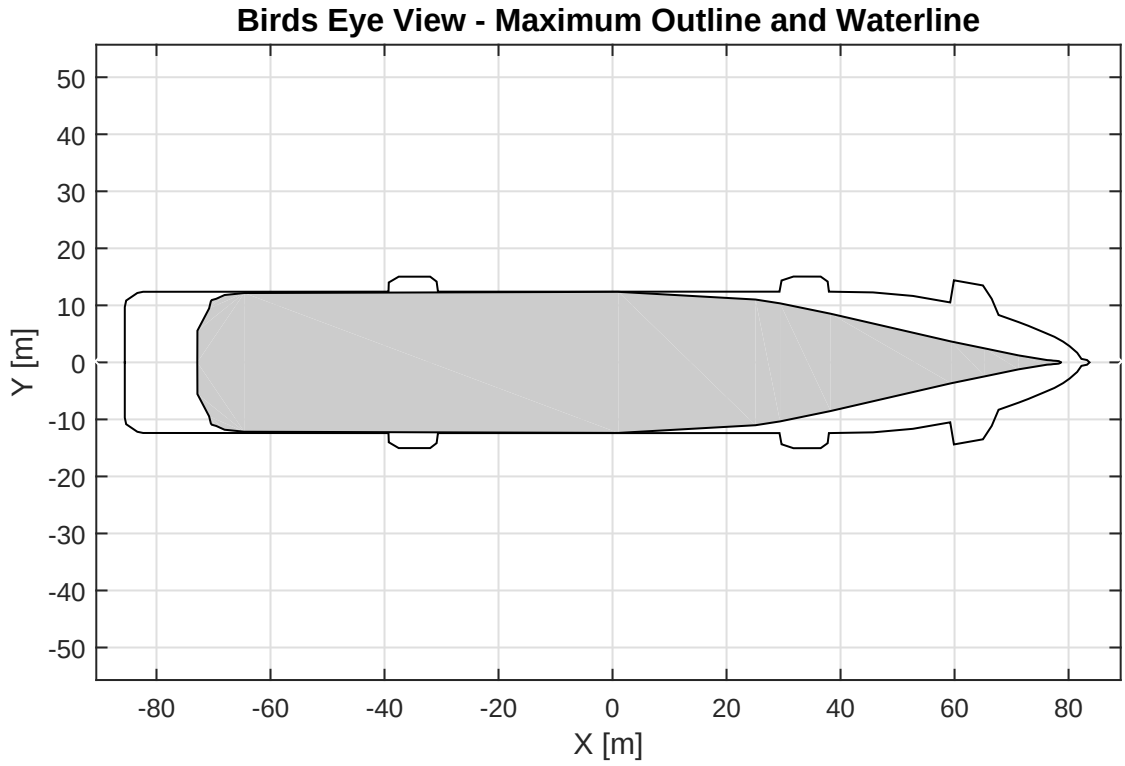
Appendix A

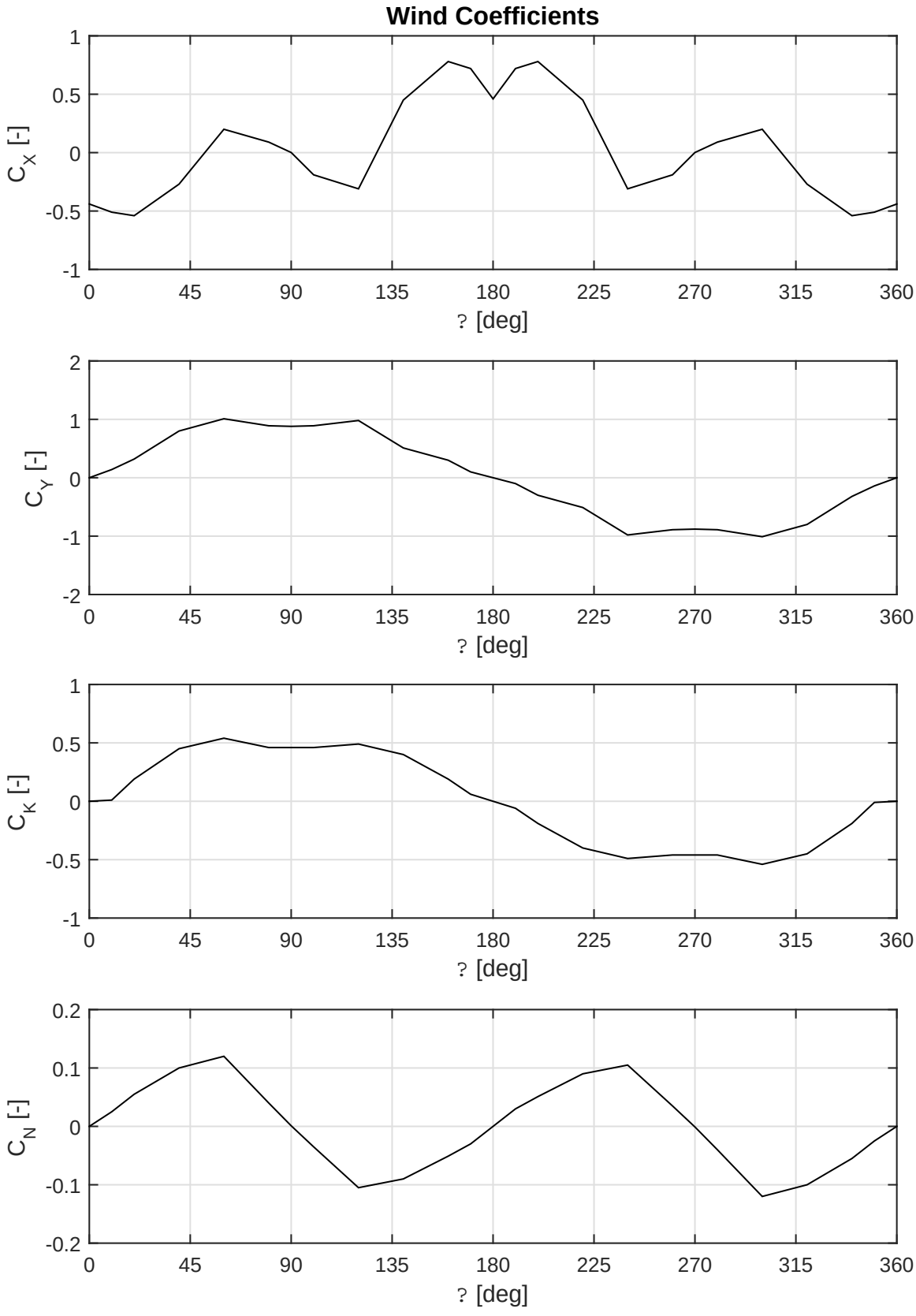
Mathematical Ship Model No. 3789 Copenhagen

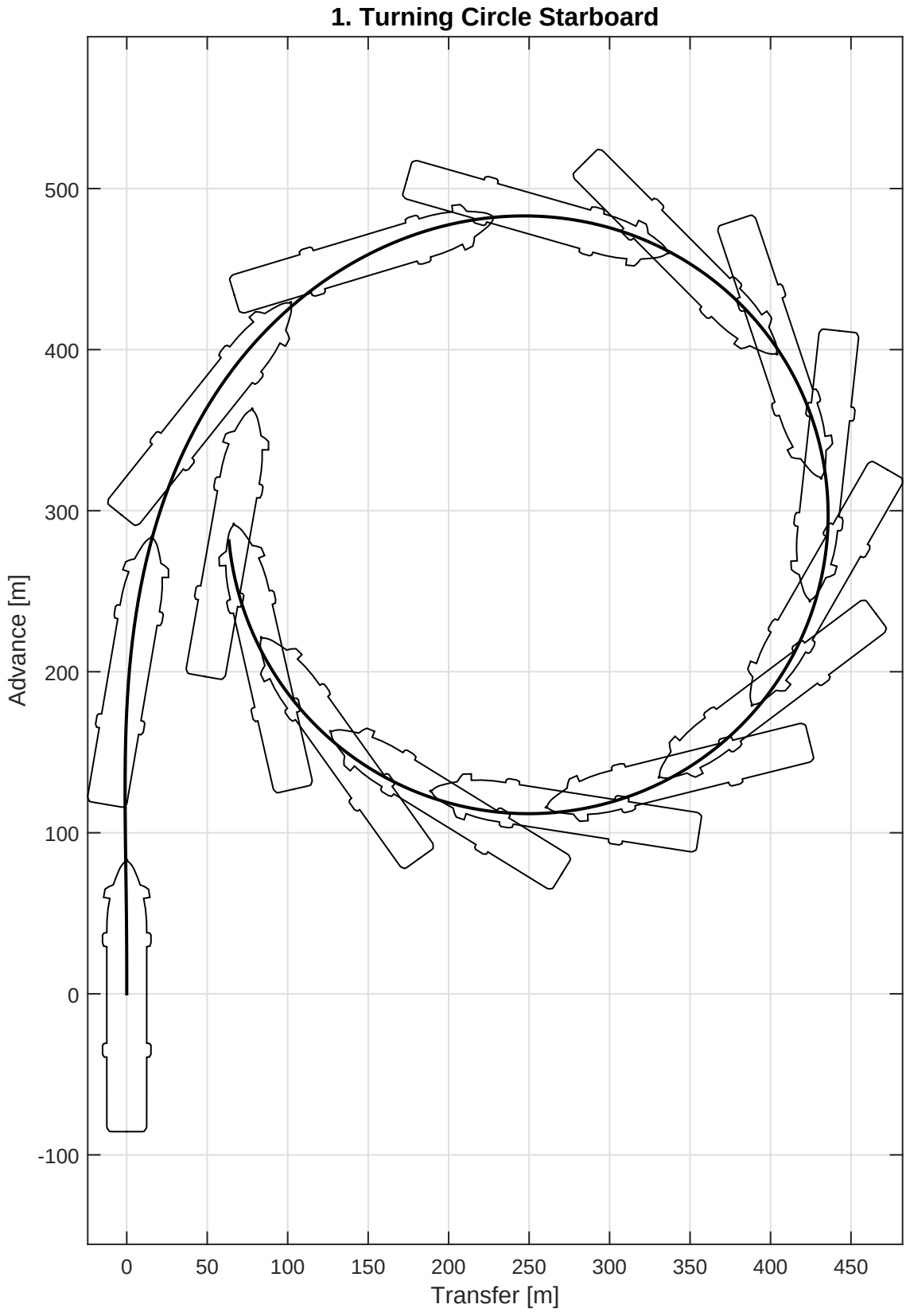
Plots of Standard and Check Manoeuvres

List of Contents


Side View of Ship 3789
Z [m]
X [m]
60
40
20
0
-20
-40
-80
-60
-40
-20
0
20
40
60
80


Birds Eye View - Maximum Outline and Waterline
Y [m]
X [m]
50
40
30
20
10
0
-10
-20
-30
-40
-50
-80
-60
-40
-20
0
20
40
60
80


Wind Coefficients
C_X [-]
1
0.5
0
-0.5
-1
0
45
90
135
180
225
270
315
360
? [deg]
C_Y [-]
2
1
0
-1
-2
0
45
90
135
180
225
270
315
360
? [deg]
C_K [-]
1
0.5
0
-0.5
-1
0
45
90
135
180
225
270
315
360
? [deg]
C_N [-]
0.2
0.1
0
-0.1
-0.2
0
45
90
135
180
225
270
315
360
? [deg]


1. Turning Circle Starboard
Advance [m]
Transfer [m]
500
400
300
200
100
0
-100
0
50
100
150
200
250
300
350
400
450

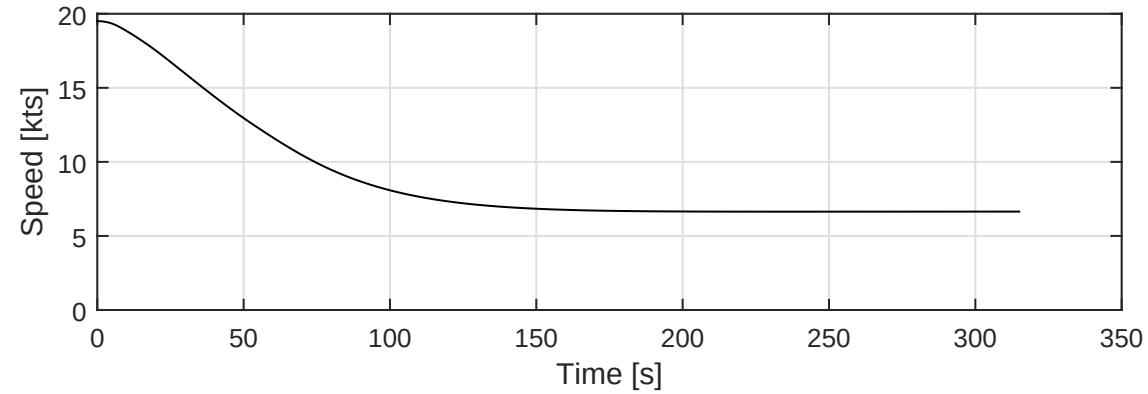
1. Turning Circle Starboard

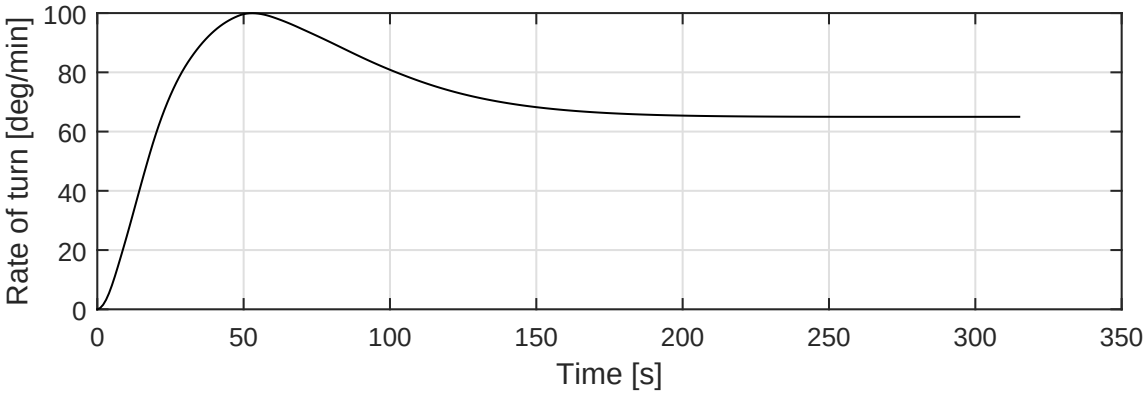
Initial Conditions and Controls

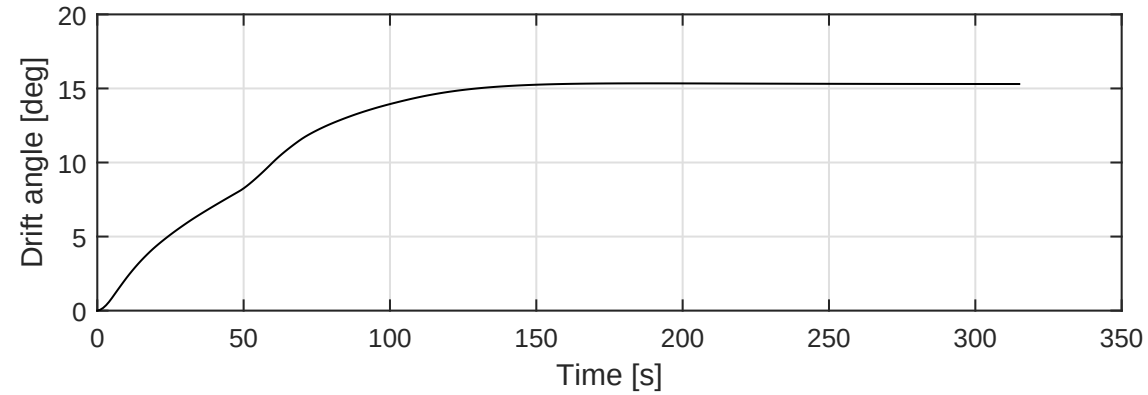
Approach speed	: 19.5 knots
Rudder deflection	: -35 deg
Water depth	: h/T = 1

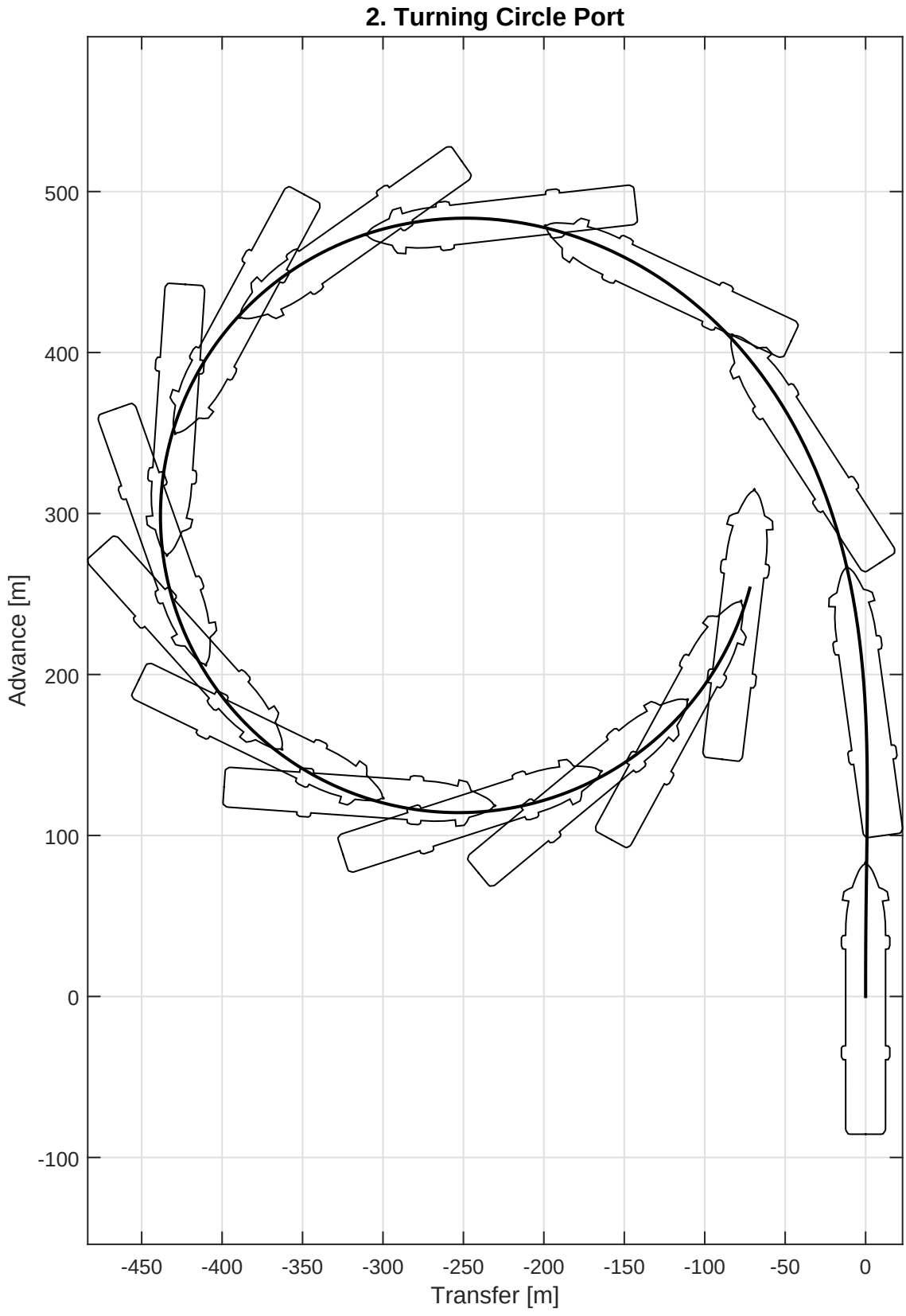
Results and Equilibrium Values

Advance	: 478 m
Transfer	: 201 m
Tactical diameter	: 430 m
Steady diameter	: 366 m








2. Turning Circle Port
Advance [m]
500
400
300
200
100
0
-100
-450
-400
-350
-300
-250
-200
-150
-100
-50
0
Transfer [m]

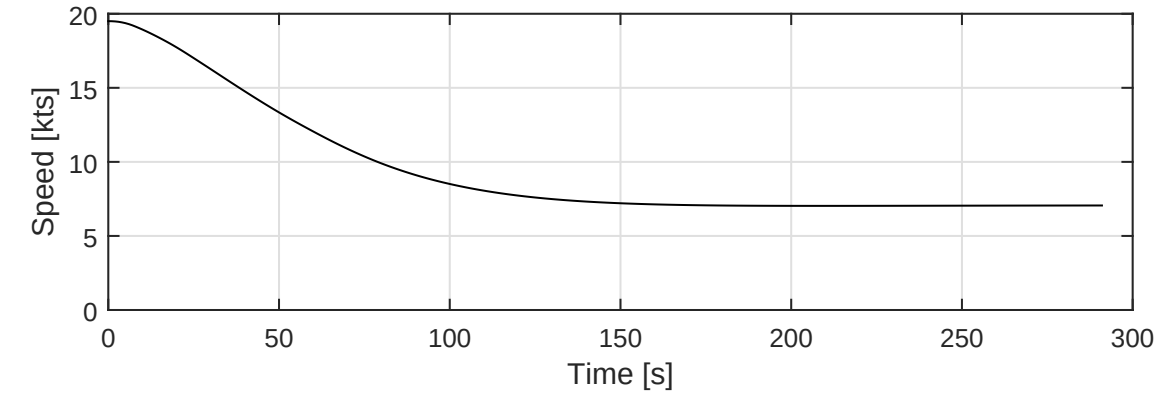
2. Turning Circle Port

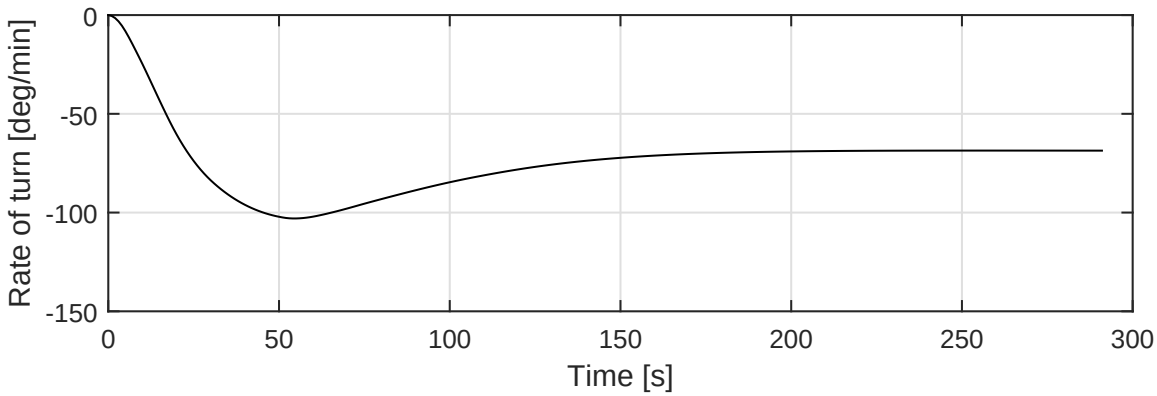
Initial Conditions and Controls

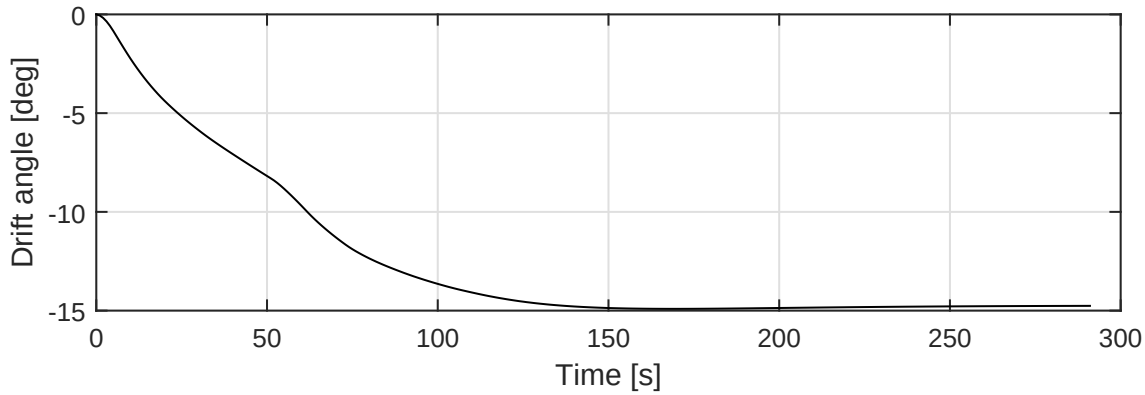
Approach speed	: 19.5 knots
Rudder deflection	: 35 deg
Water depth	: h/T = 1

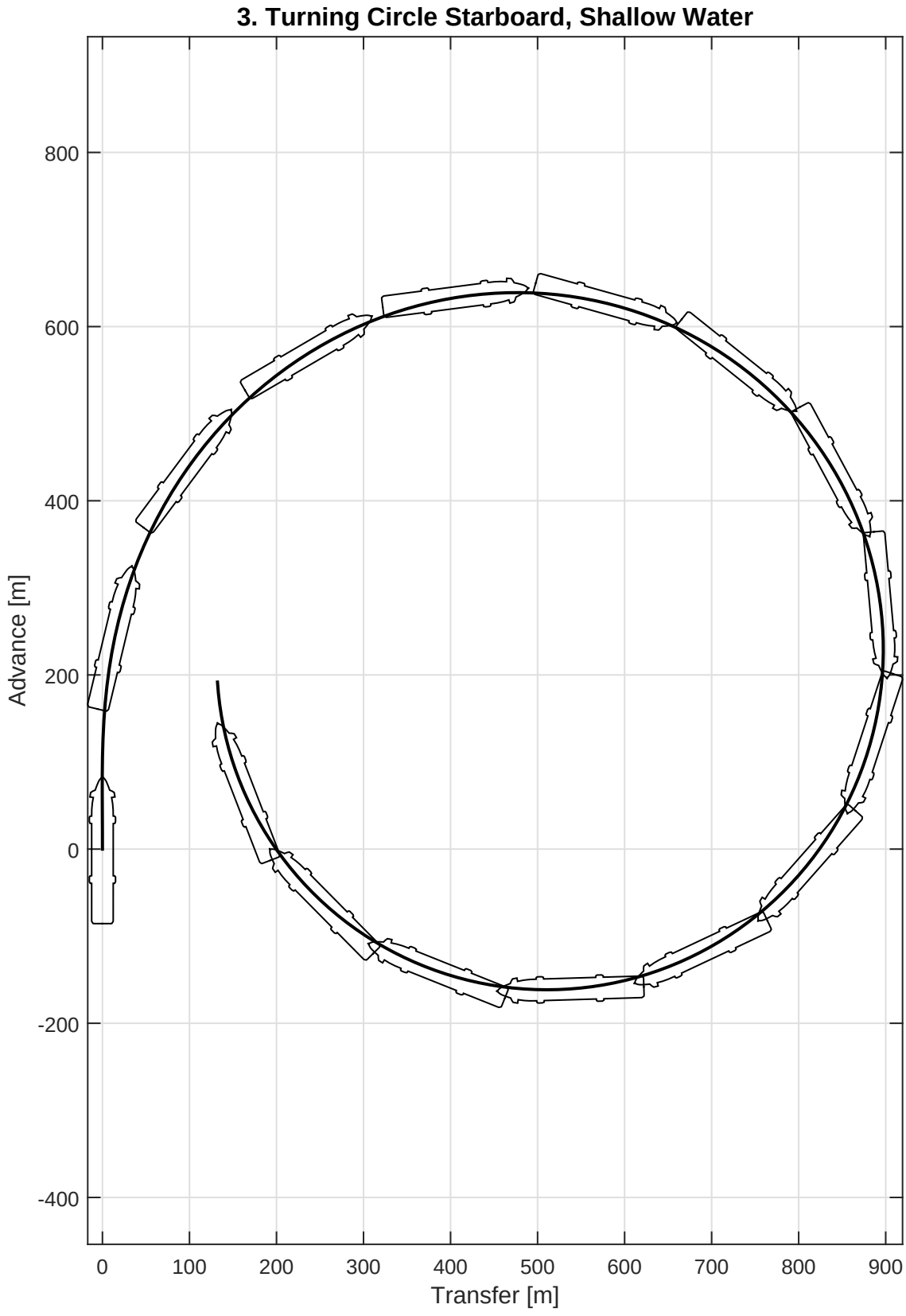
Results and Equilibrium Values

Advance	: 479 m
Transfer	: 206 m
Tactical diameter	: 432 m
Steady diameter	: 364 m








3. Turning Circle Starboard, Shallow Water
Advance [m]
Transfer [m]
800
600
400
200
0
-200
-400
0
100
200
300
400
500
600
700
800
900

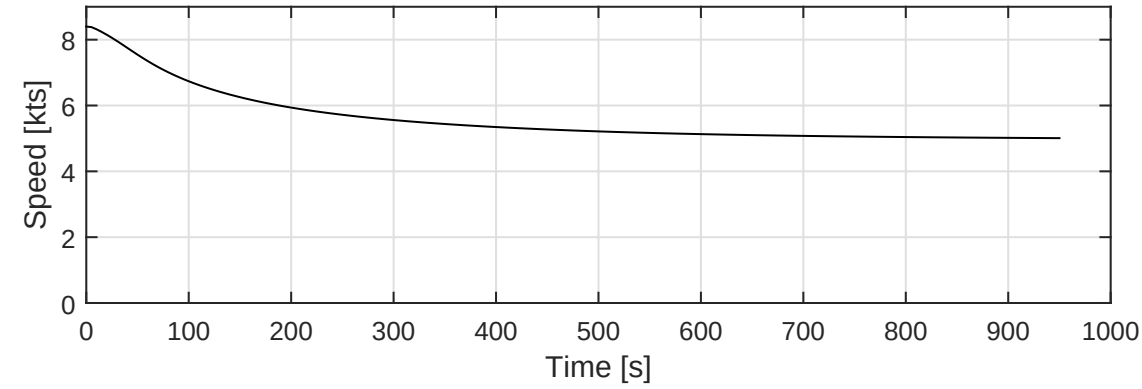
3. Turning Circle Starboard, Shallow Water

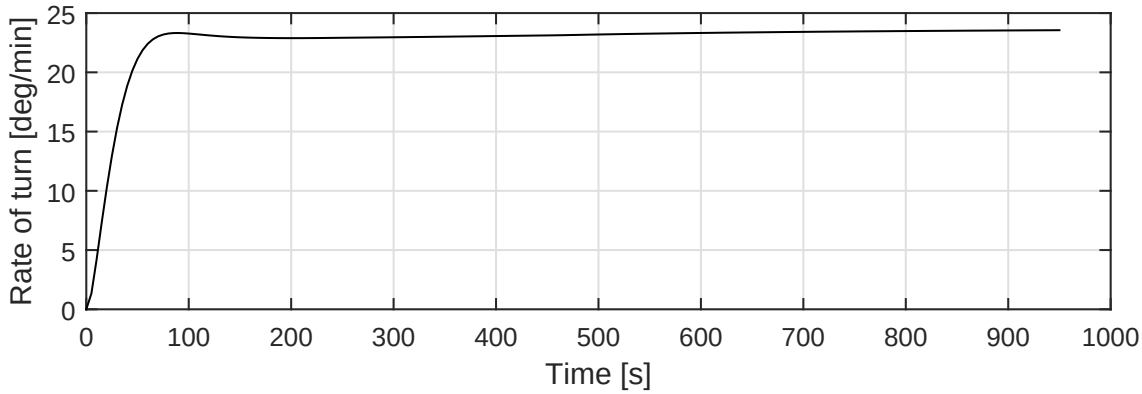
Initial Conditions and Controls

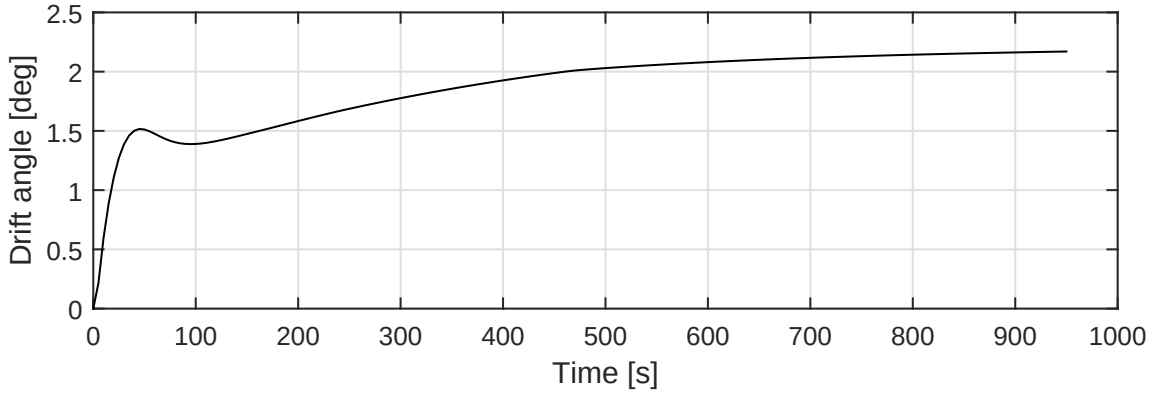
Approach speed	: 8.4 knots
Rudder deflection	: -35 deg
Water depth	: h/T = 1.2

Results and Equilibrium Values

Advance	: 639 m
Transfer	: 466 m
Tactical diameter	: 897 m
Steady diameter	: 765 m







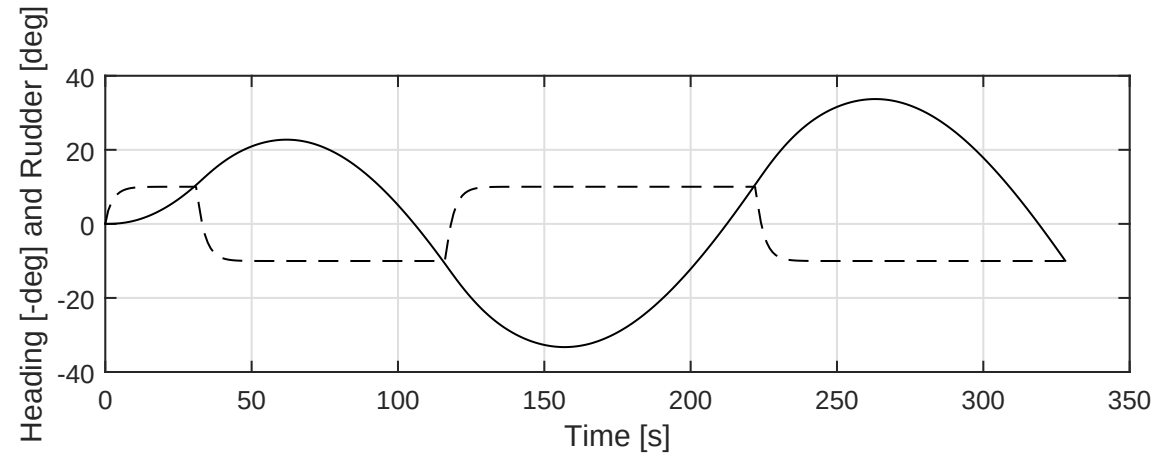
4. Zig-zag 10/10

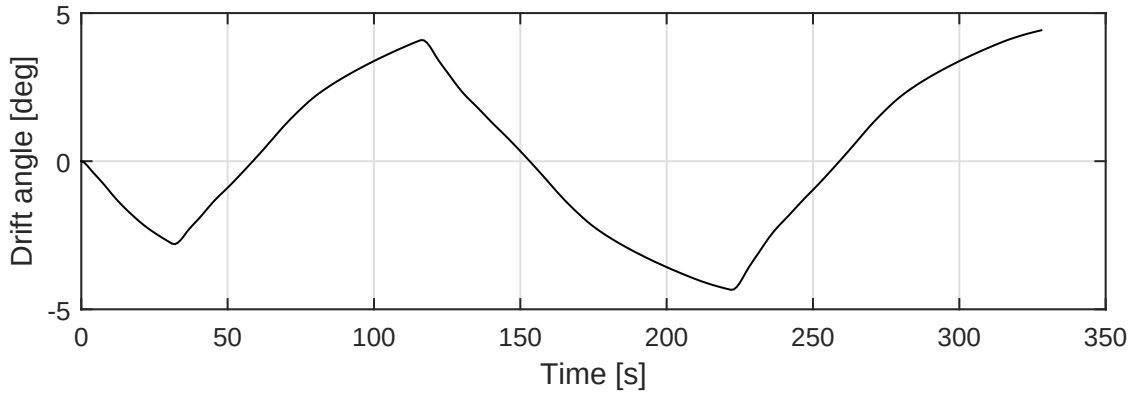
Initial Conditions and Controls

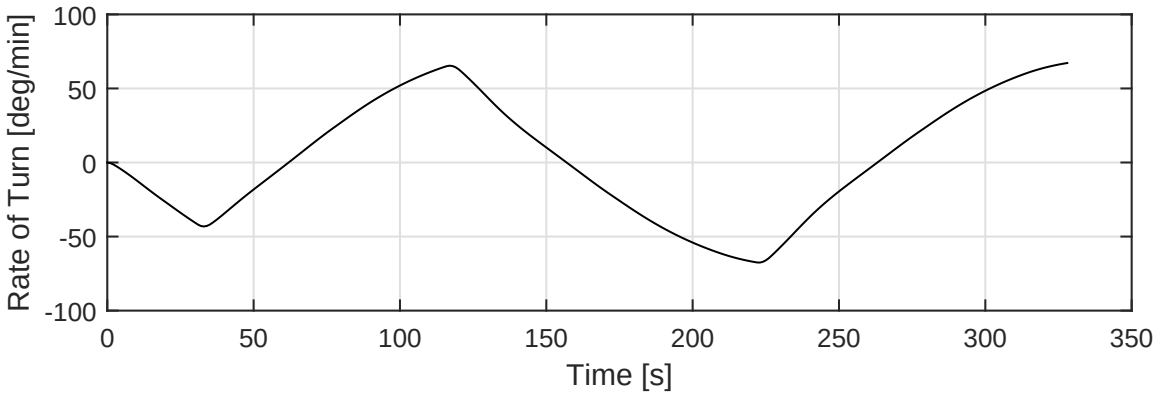
Approach speed	: 19.5 knots
Rudder/heading deflection	: 10/10 deg

Results and Equilibrium Values

1st Overshoot Angle	: 12.7 deg
2nd Overshoot Angle	: 23.3 deg
Initial turning ability	: 298 m







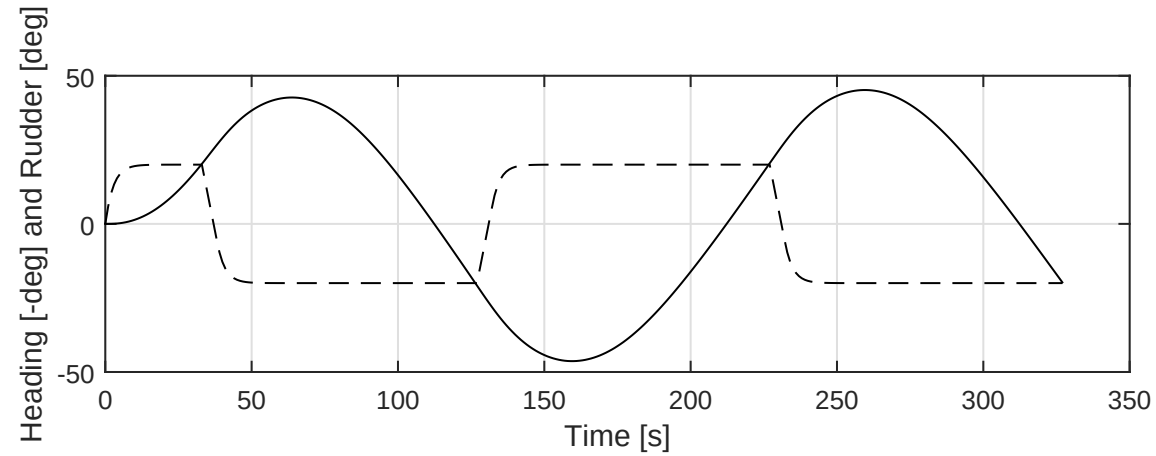
5. Zig-zag 20/20

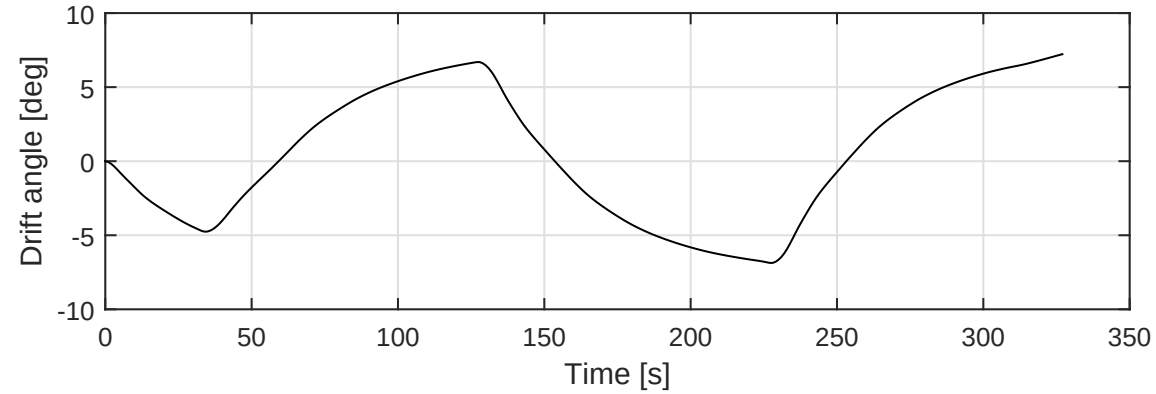
Initial Conditions and Controls

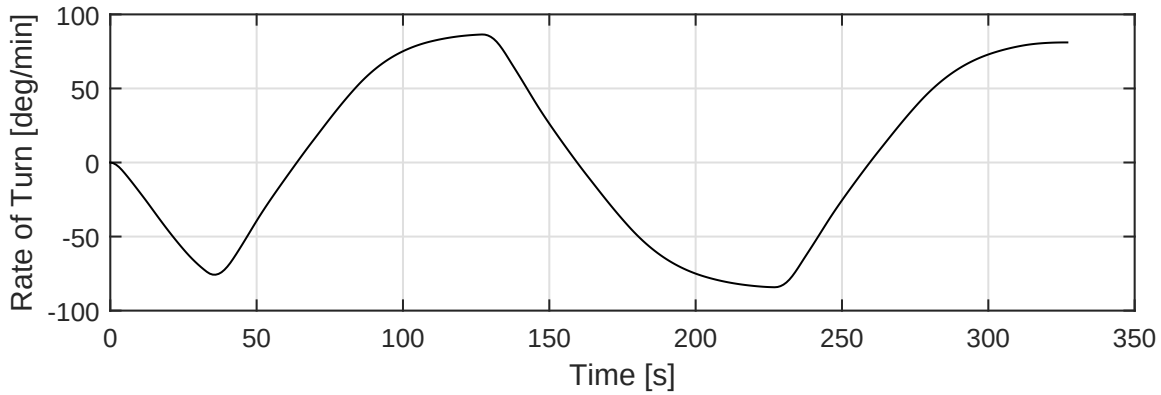
Approach speed	: 19.5 knots
Rudder/heading deflection	: 20/20 deg

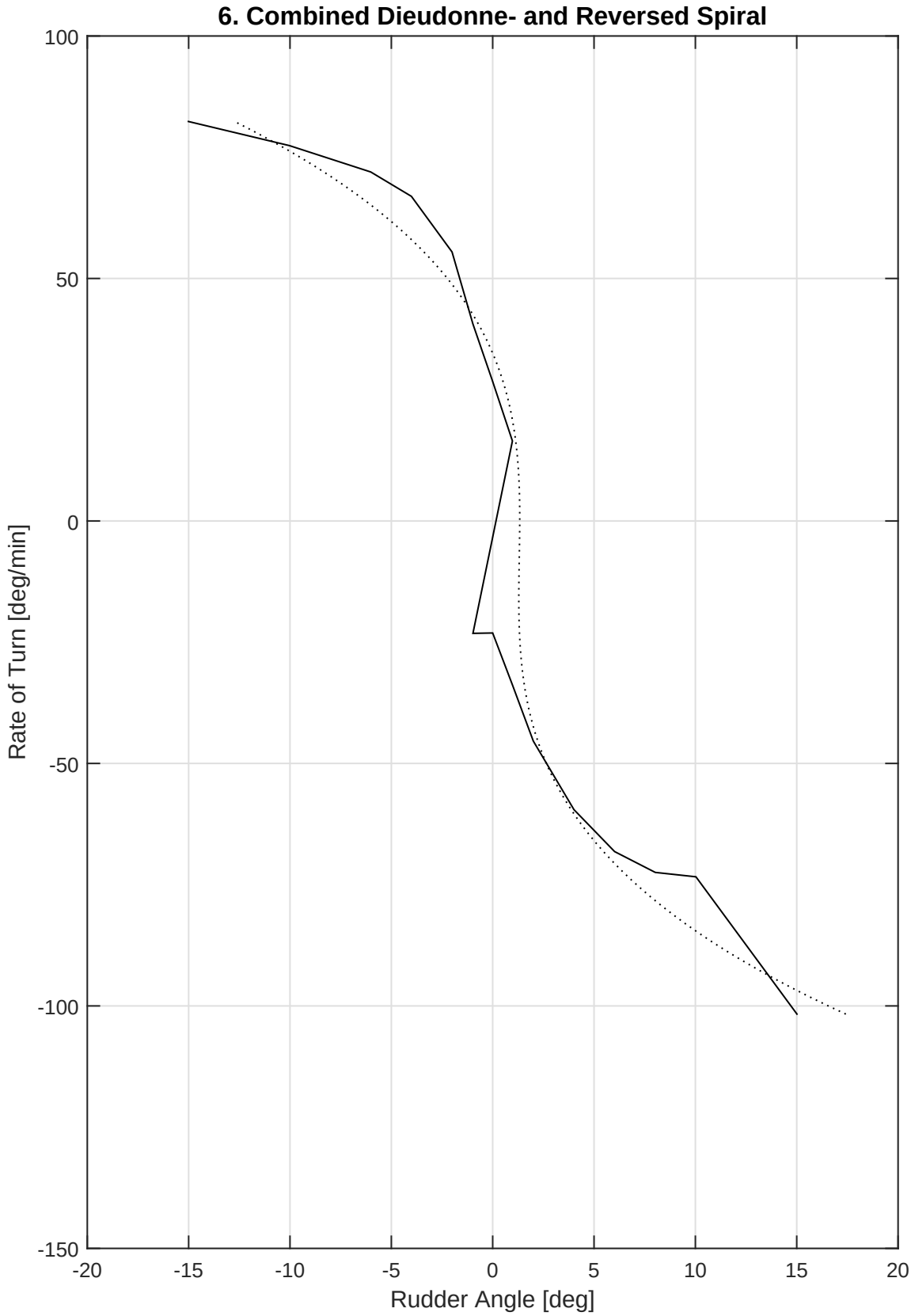
Results and Equilibrium Values

1st Overshoot Angle	: 22.7 deg
2nd Overshoot Angle	: 26.3 deg
Initial turning ability	: 308 m








6. Combined Dieudonne- and Reversed Spiral
Rate of Turn [deg/min]
Rudder Angle [deg]
100
50
0
-50
-100
-150
-20
-15
-10
-5
0
5
10
15
20

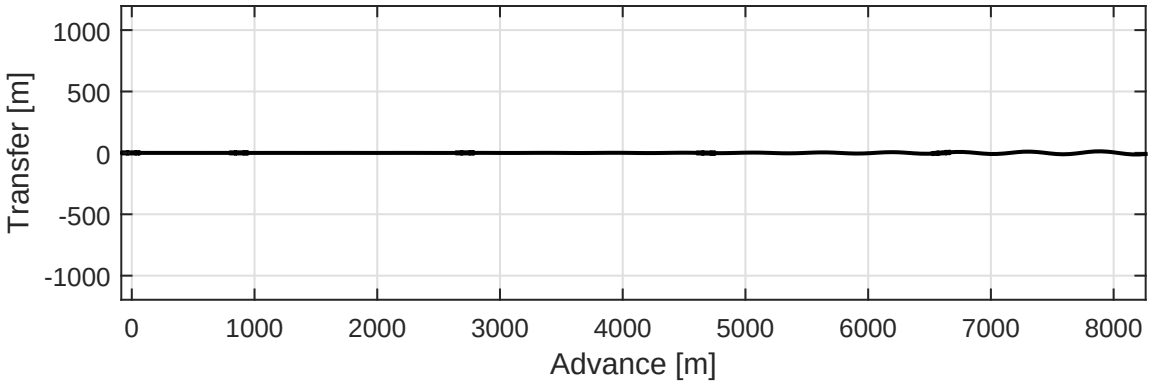
7. Acceleration

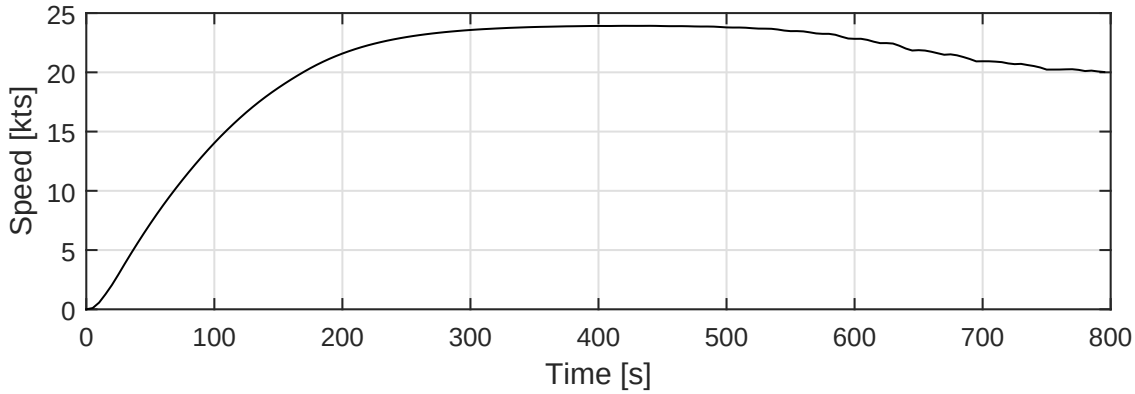
Initial Conditions and Controls

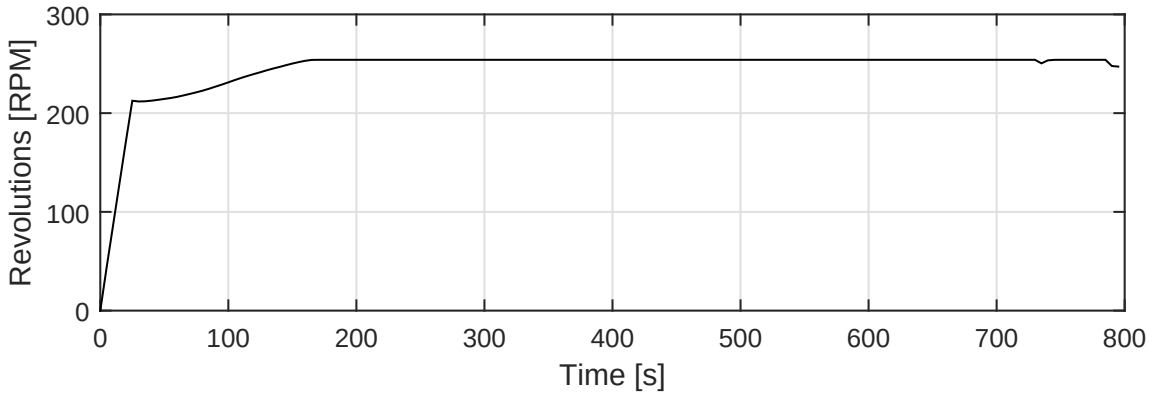
Initial speed	: 0.0 knots
Water depth	: h/T = 1

Results and Equilibrium Values

Advance	: 8261 m
Speed	: 20.0 knots
Revolutions	: 247.1 RPM
Time	: 795 s







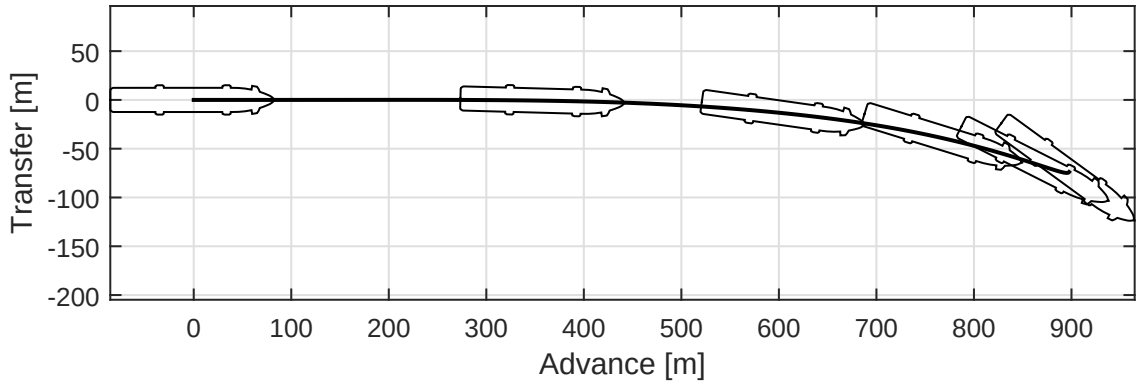
8. Standard Crash Stop

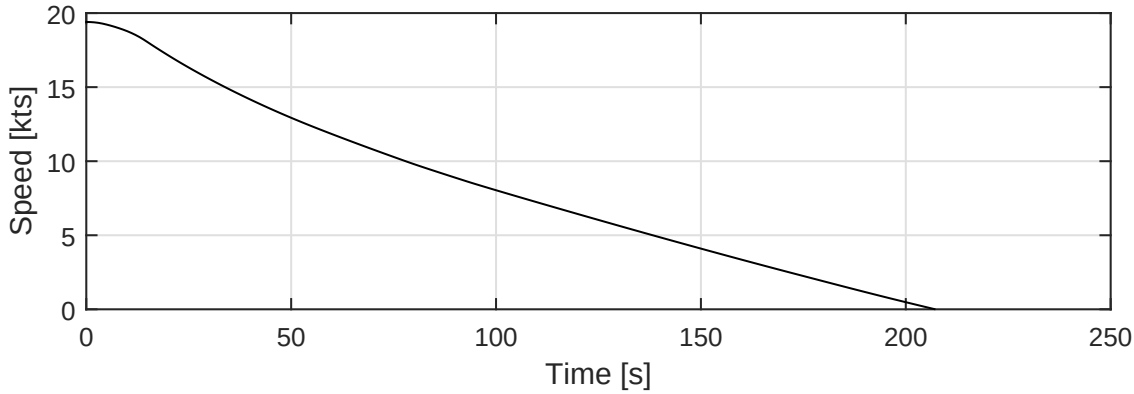
Initial Conditions and Controls

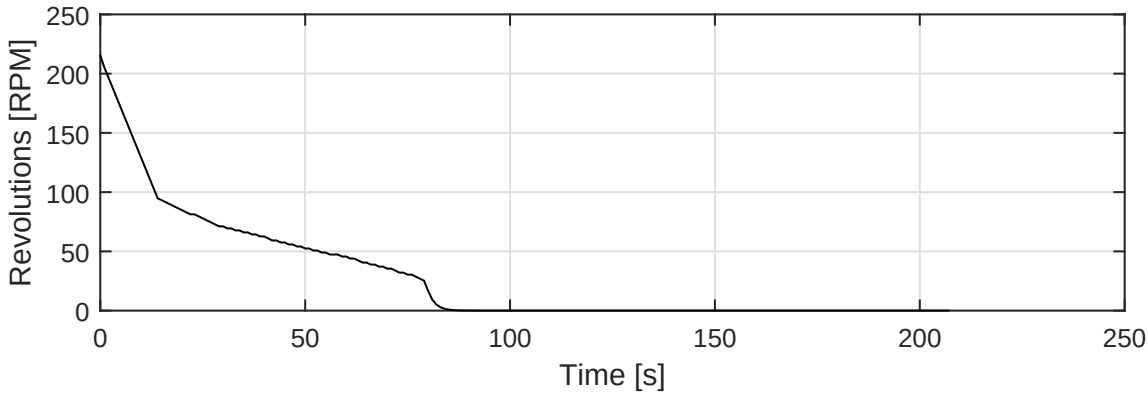
Initial speed	: 19.4 knots
Water depth	: h/T = 1

Results and Equilibrium Values

Advance	: 898 m
Speed	: 0.0 knots
Revolutions	: 0.0 RPM
Time	: 207 s







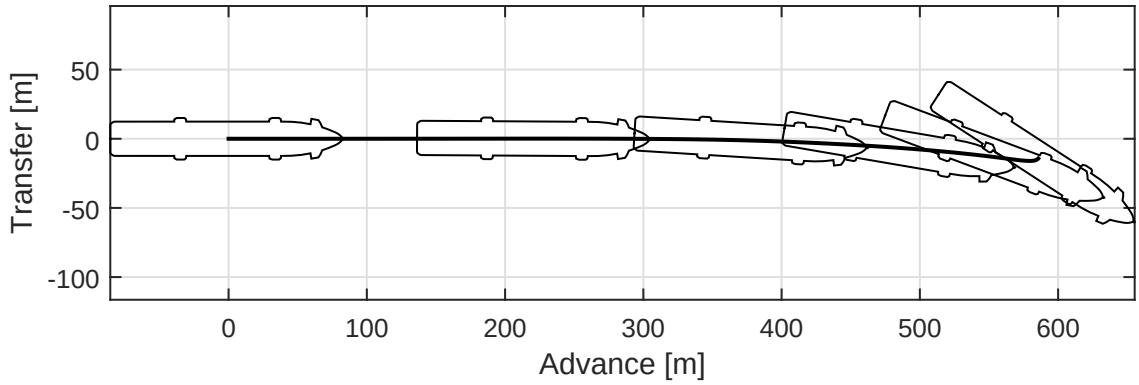
9. Azimuth Crash Stop

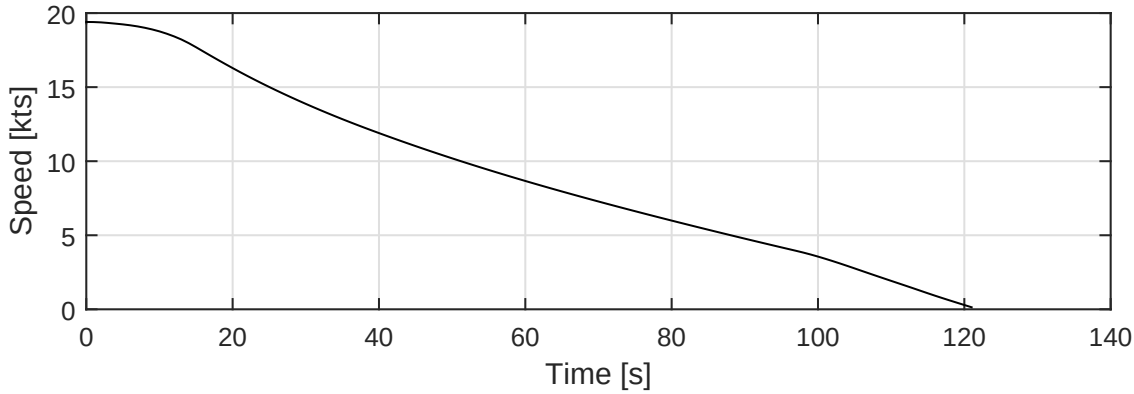
Initial Conditions and Controls

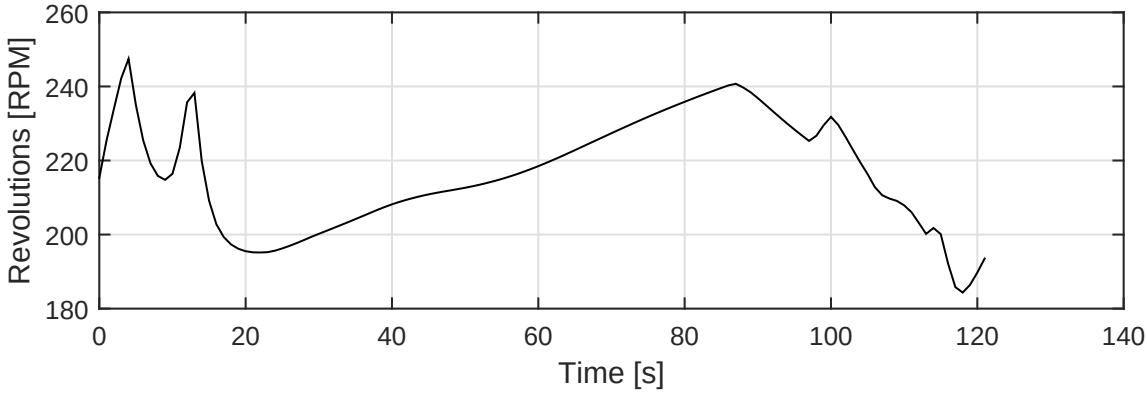
Initial speed	: 19.4 knots
Water depth	: h/T = 1

Results and Equilibrium Values

Advance	: 586 m
Speed	: 0.1 knots
Revolutions	: 193.5 RPM
Time	: 121 s







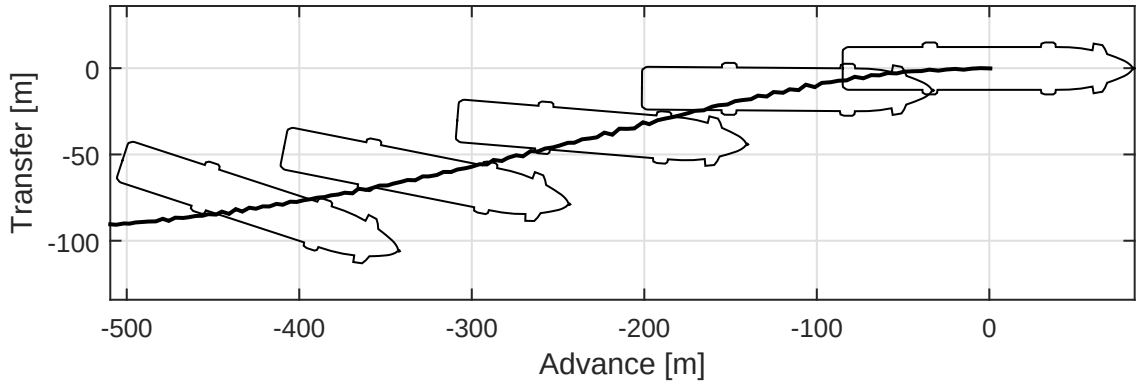
10. Going Astern

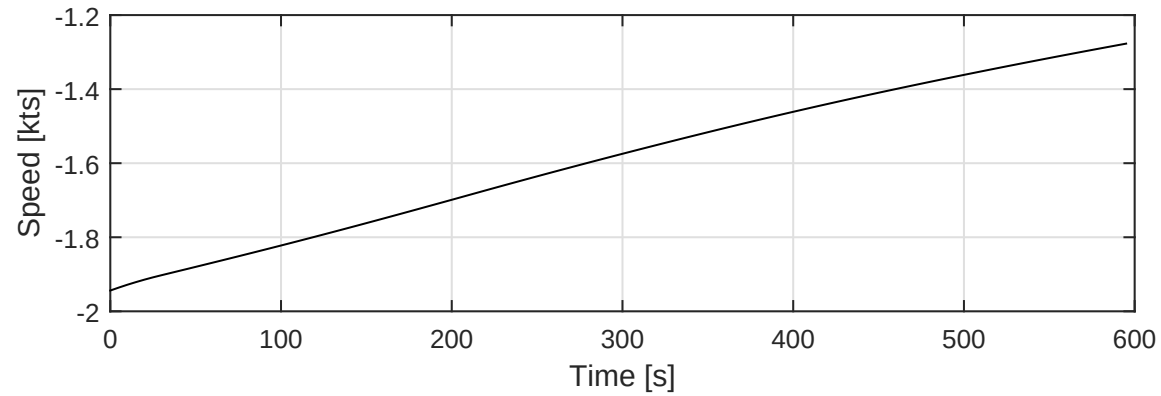
Initial Conditions and Controls

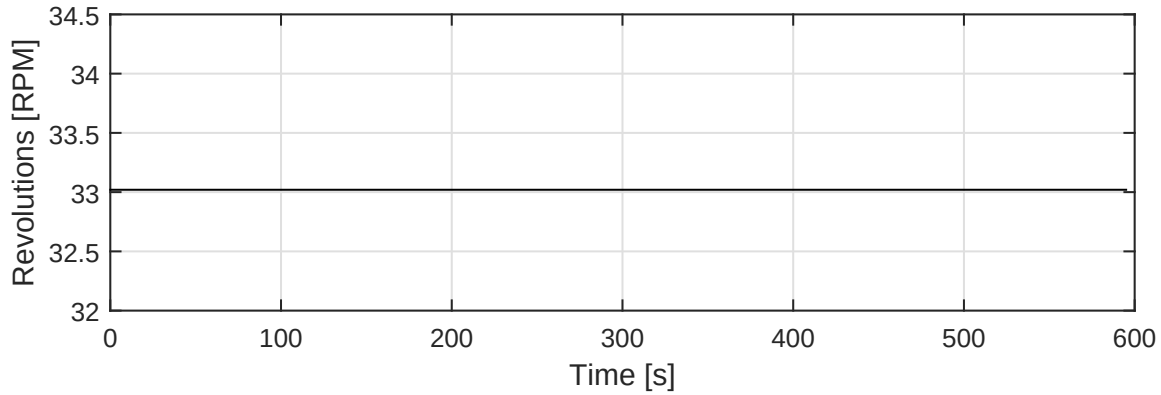
Initial speed	: -1.9 knots
Water depth	: h/T = 1

Results and Equilibrium Values

Advance	: -510 m
Speed	: -1.3 knots
Revolutions	: 33.0 RPM
Time	: 595 s







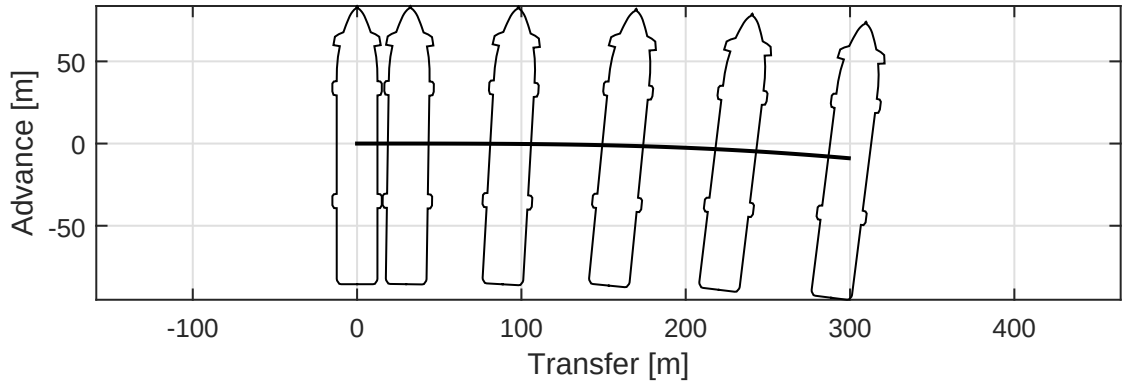
11. Drifting in Wind

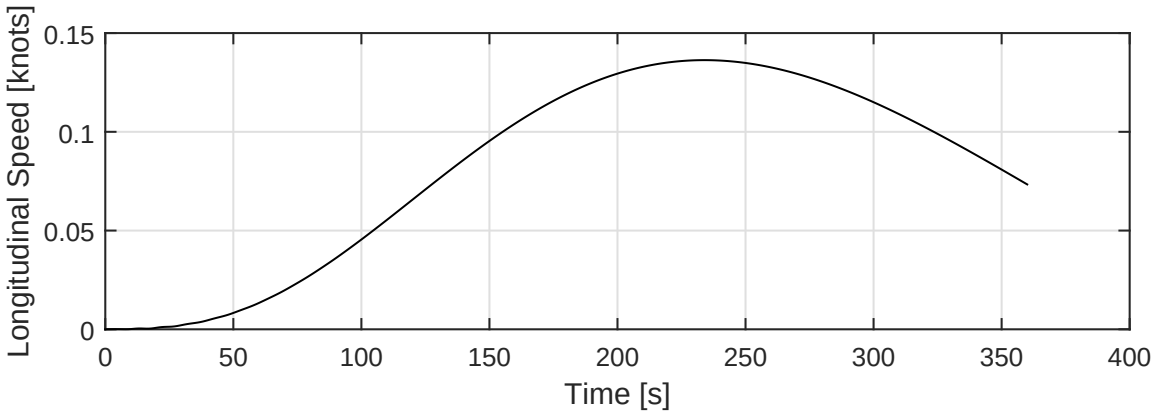
Initial Conditions and Controls

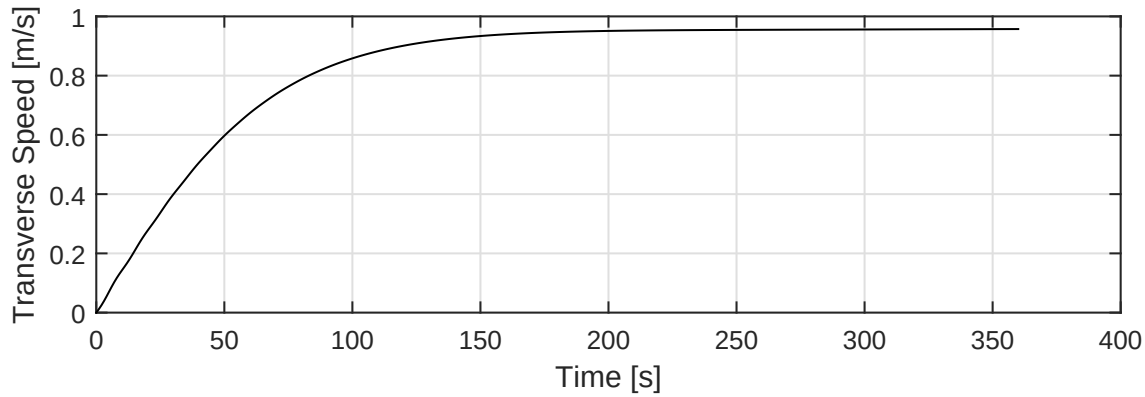
Water depth	: h/T = 1
Wind speed	: 15 m/s
Wind direction	: 270 deg

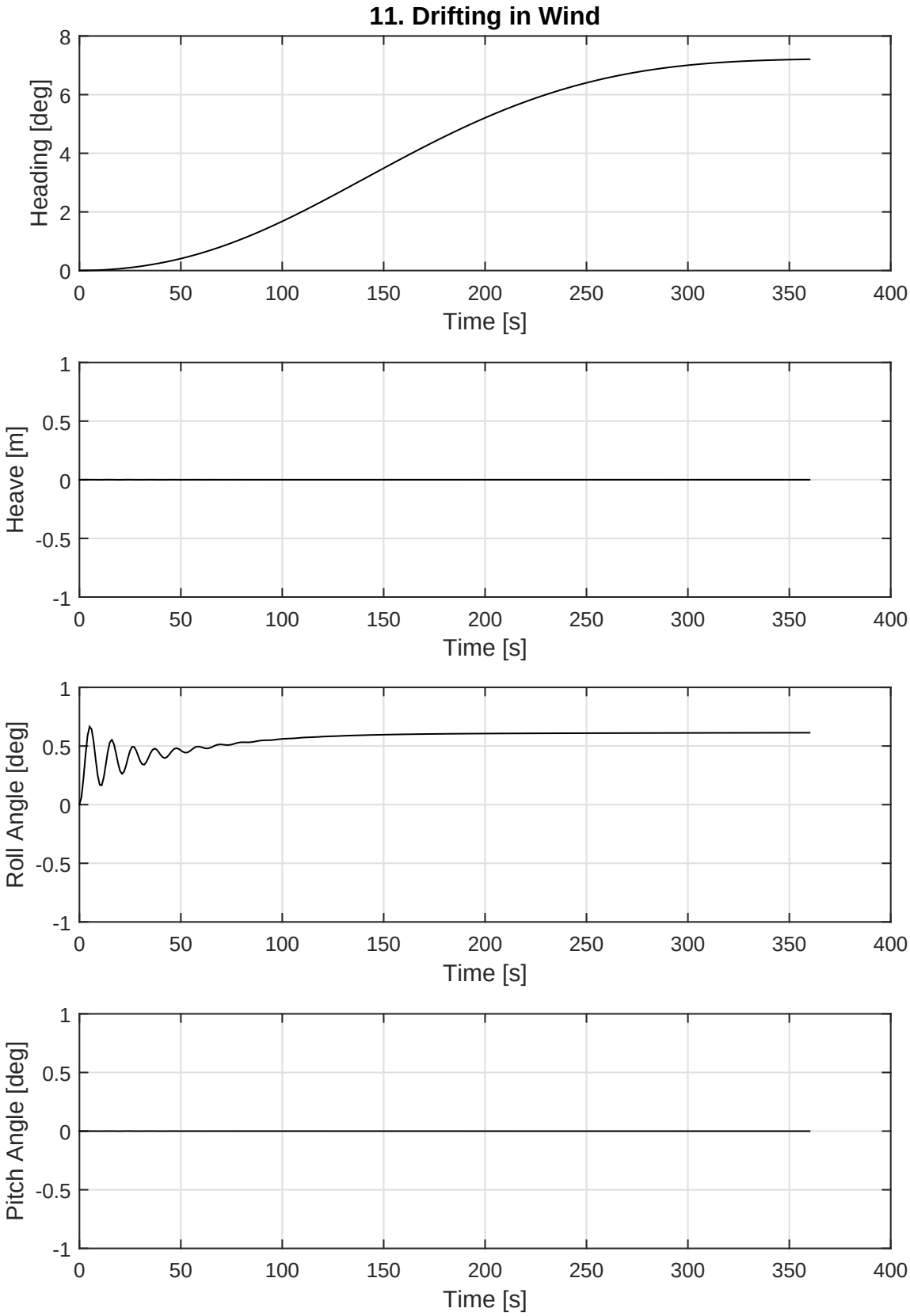
Results and Equilibrium Values

Longitudinal Speed	: 0.1 knots
Transverse Speed	: 1.0 m/s
Roll Angle	: 0.6 deg








11. Drifting in Wind
Heading [deg]
Time [s]
Heave [m]
Time [s]
Roll Angle [deg]
Time [s]
Pitch Angle [deg]
Time [s]

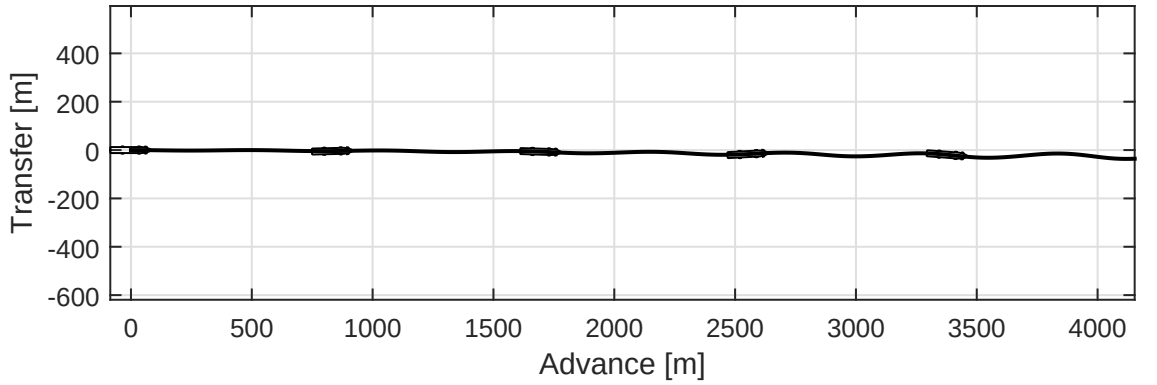
12. Sailing with Autopilot in Wind

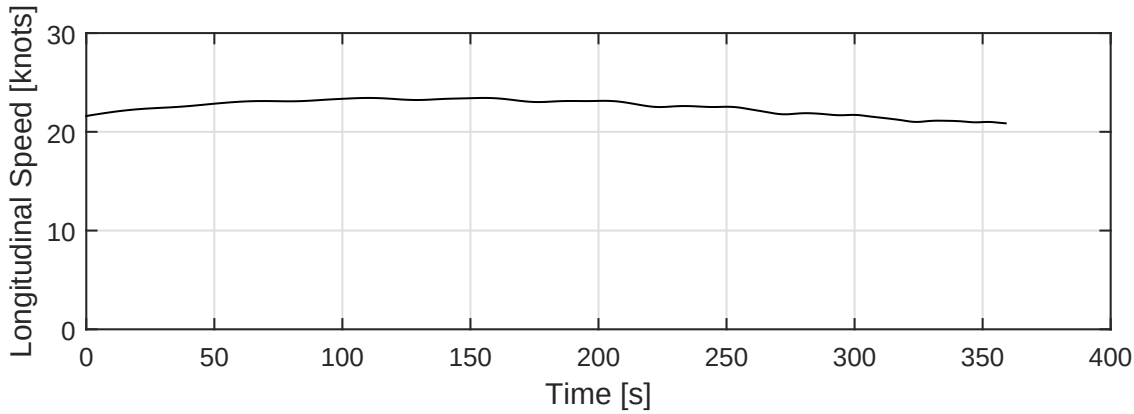
Initial Conditions and Controls

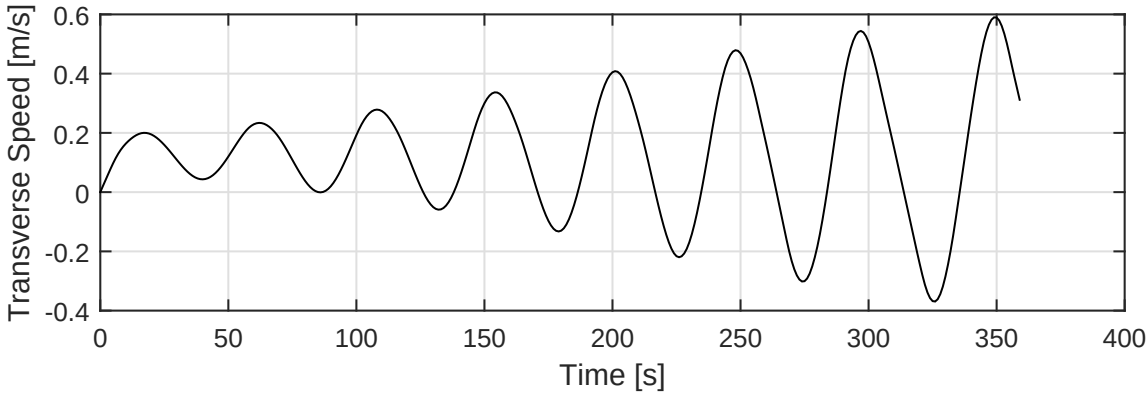
Water depth	: h/T = 1
Wind speed	: 15 m/s
Wind direction	: 270 deg

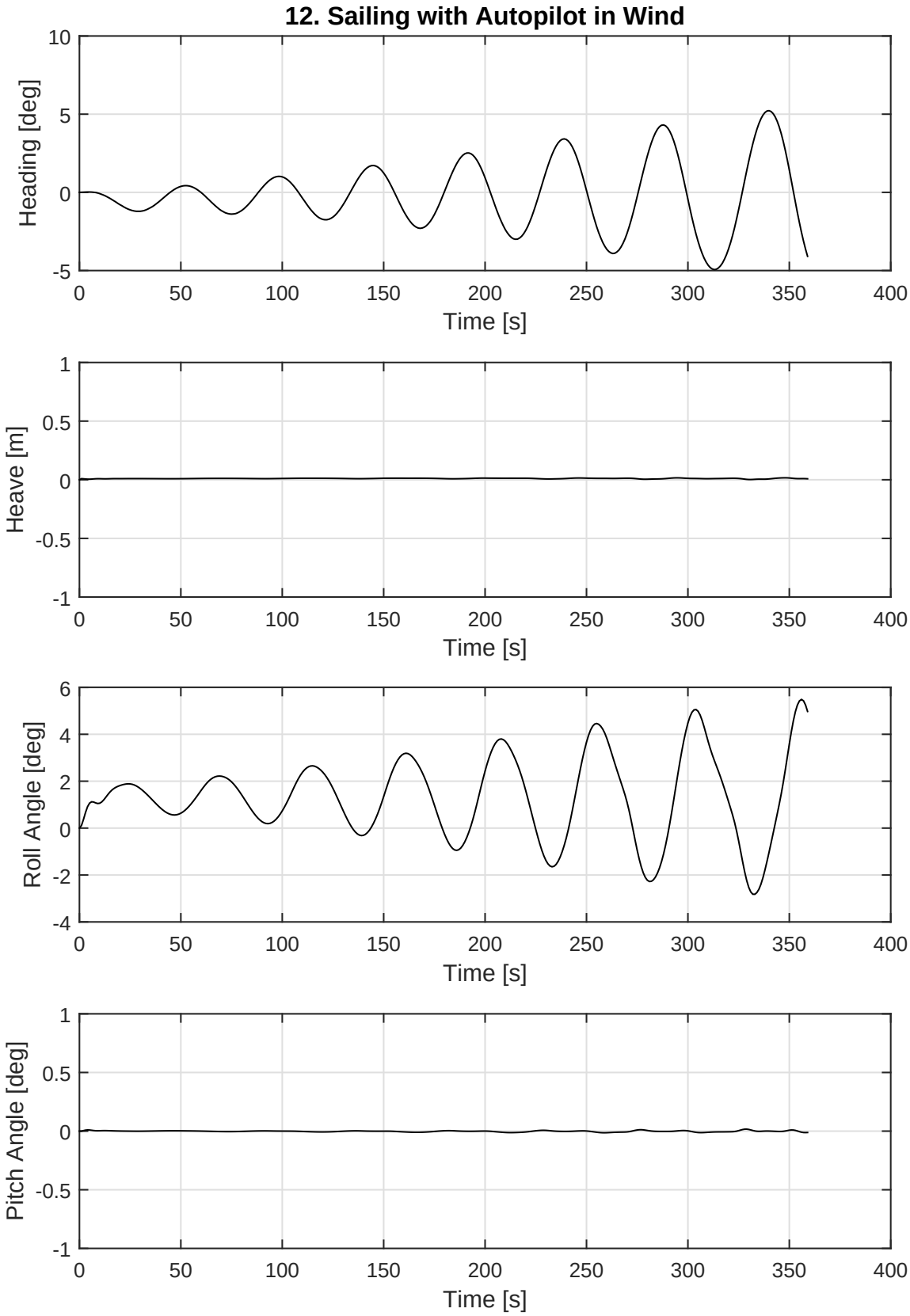
Results and Equilibrium Values

Longitudinal Speed	: 20.9 knots
Transverse Speed	: 0.3 m/s
Roll Angle	: 5.0 deg








12. Sailing with Autopilot in Wind
Heading [deg]
Time [s]
Heave [m]
Time [s]
Roll Angle [deg]
Time [s]
Pitch Angle [deg]
Time [s]

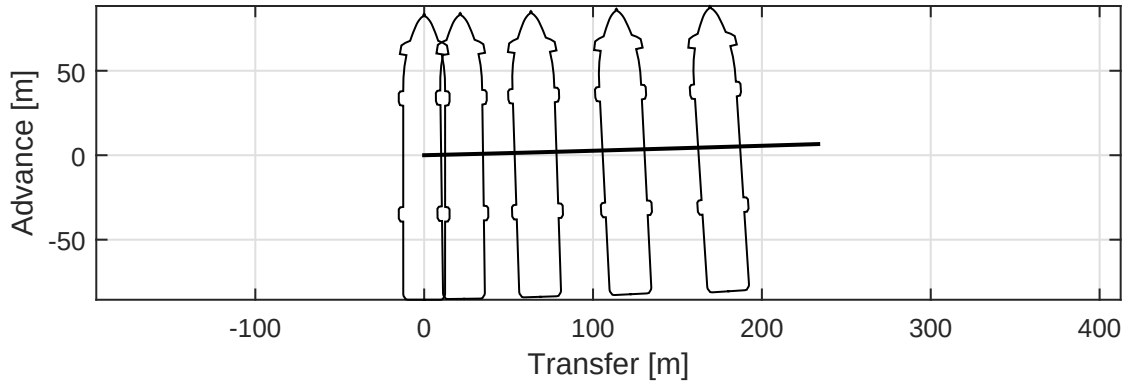
13. Drifting in Current

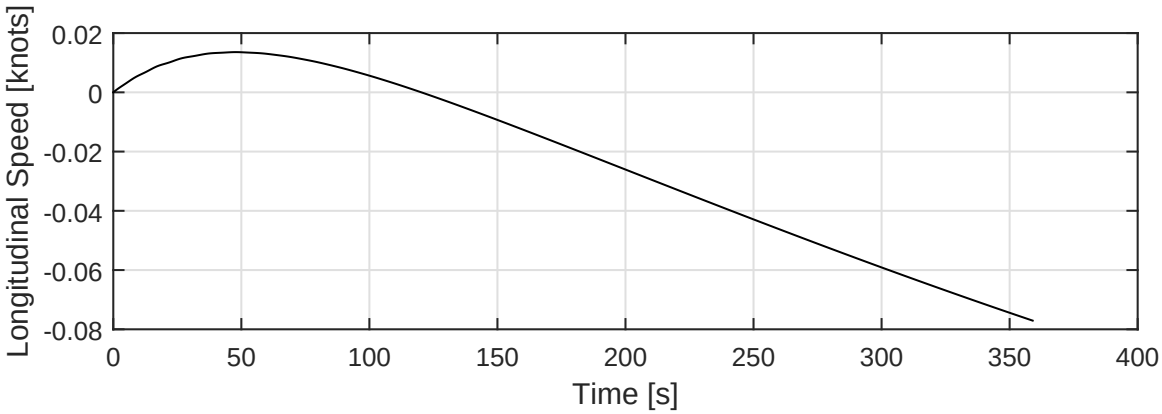
Initial Conditions and Controls

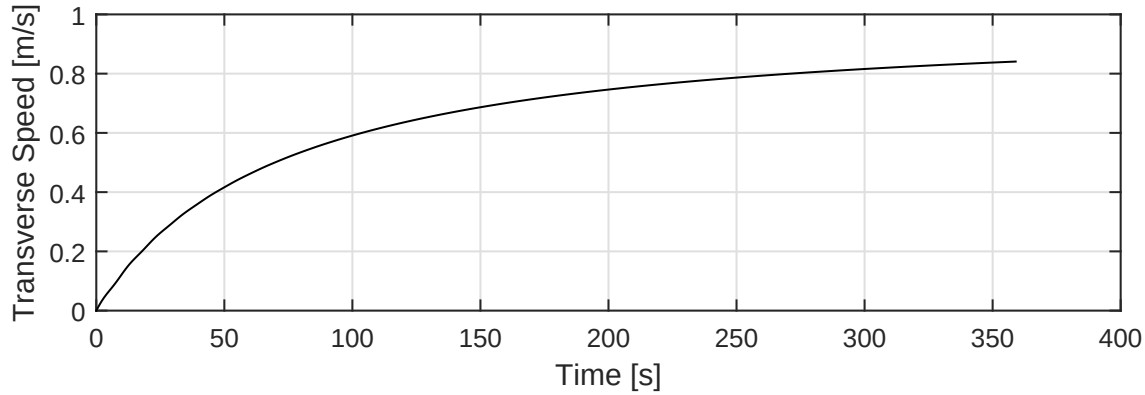
Water depth	: h/T = 1
Current speed	: 2 knots
Current direction	: 90 deg

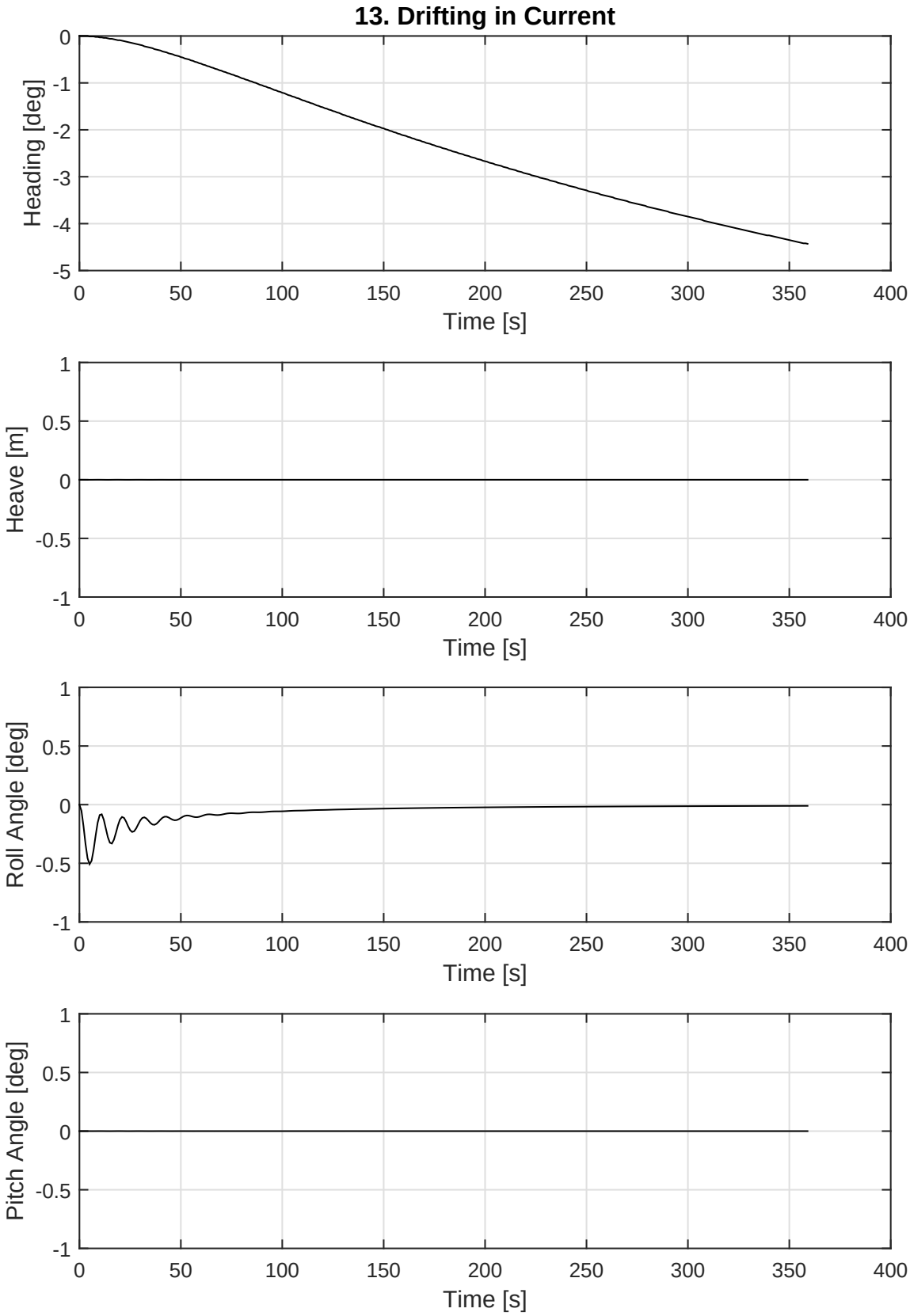
Results and Equilibrium Values

Longitudinal Speed	: -0.1 knots
Transverse Speed	: 0.8 m/s
Roll Angle	: -0.0 deg








13. Drifting in Current
Heading [deg]
Time [s]
Heave [m]
Time [s]
Roll Angle [deg]
Time [s]
Pitch Angle [deg]
Time [s]

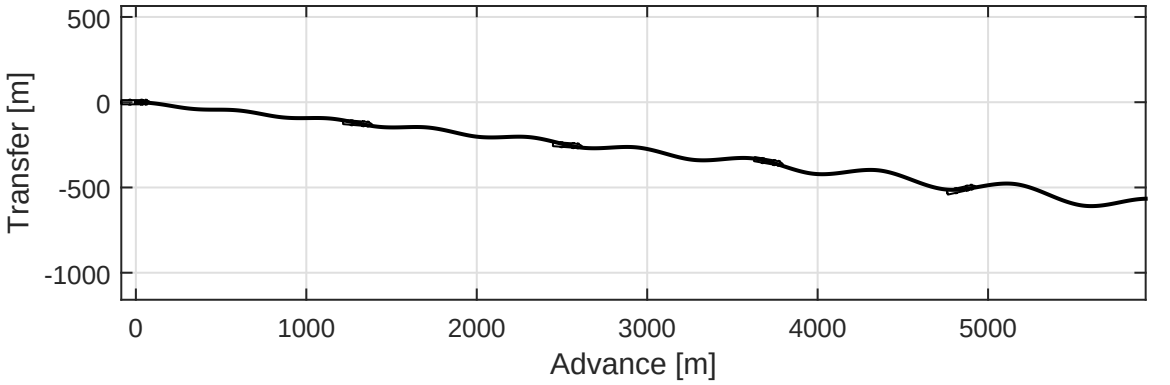
14. Sailing with Autopilot in Current

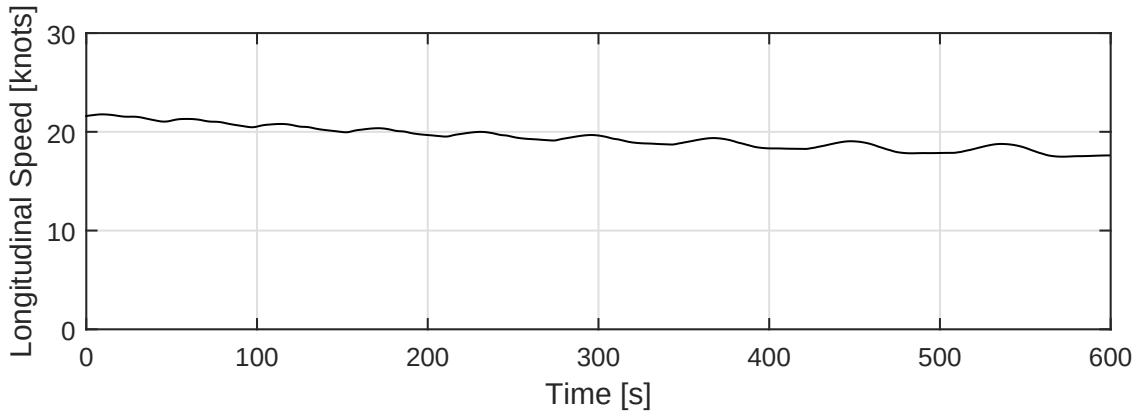
Initial Conditions and Controls

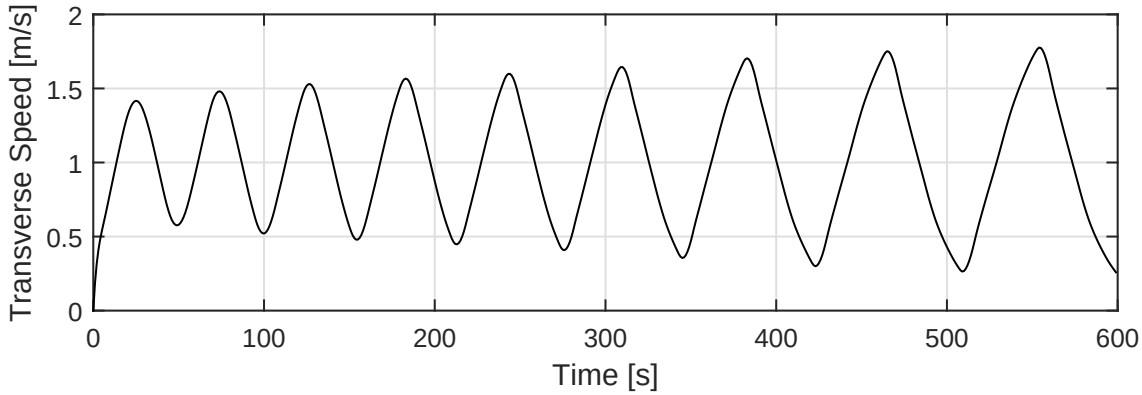
Water depth	: h/T = 1
Current speed	: 2 knots
Current direction	: 90 deg

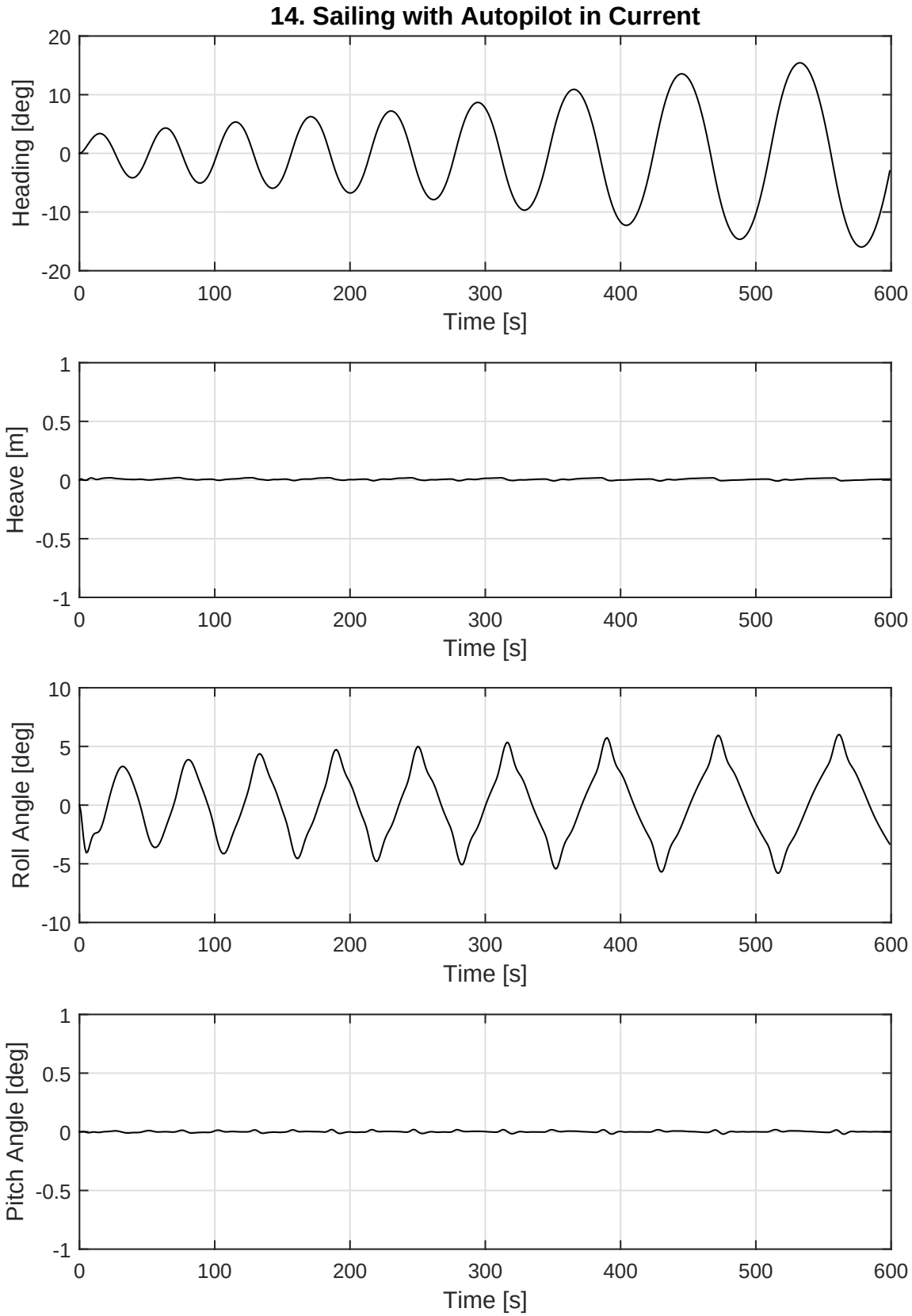
Results and Equilibrium Values

Longitudinal Speed	: 17.6 knots
Transverse Speed	: 0.3 m/s
Roll Angle	: -3.3 deg








14. Sailing with Autopilot in Current
Heading [deg]
Time [s]
Heave [m]
Time [s]
Roll Angle [deg]
Time [s]
Pitch Angle [deg]
Time [s]

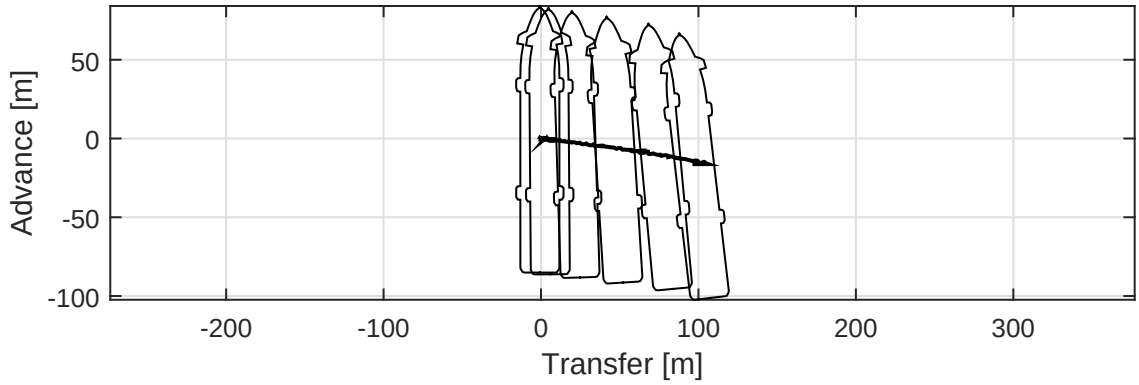
15. Drifting in Waves

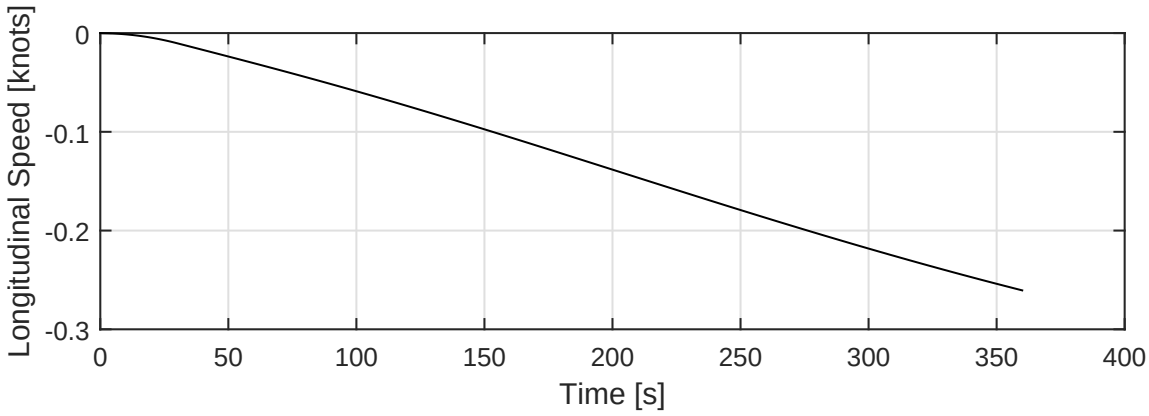
Initial Conditions and Controls

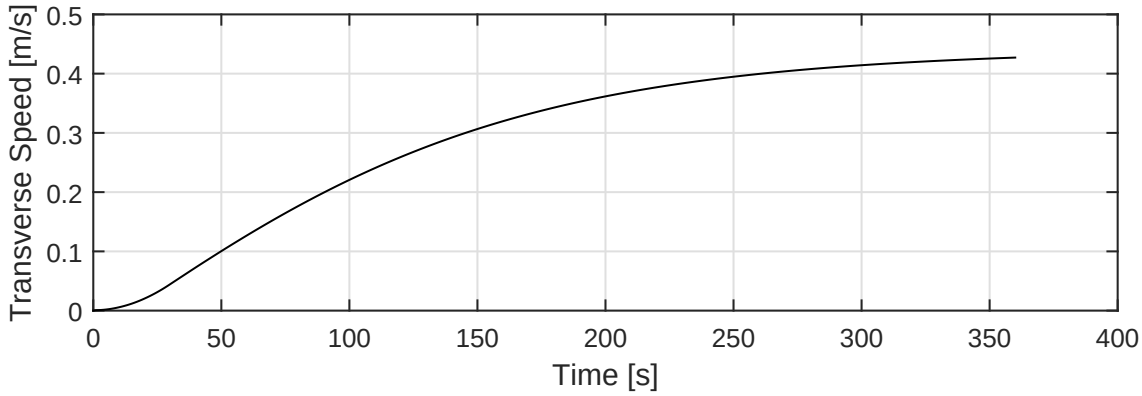
Water depth	: h/T = 1
Wave height (Hs)	: 3 m
Wave period (Tp)	: 9.1 s
Wave direction	: 90 deg

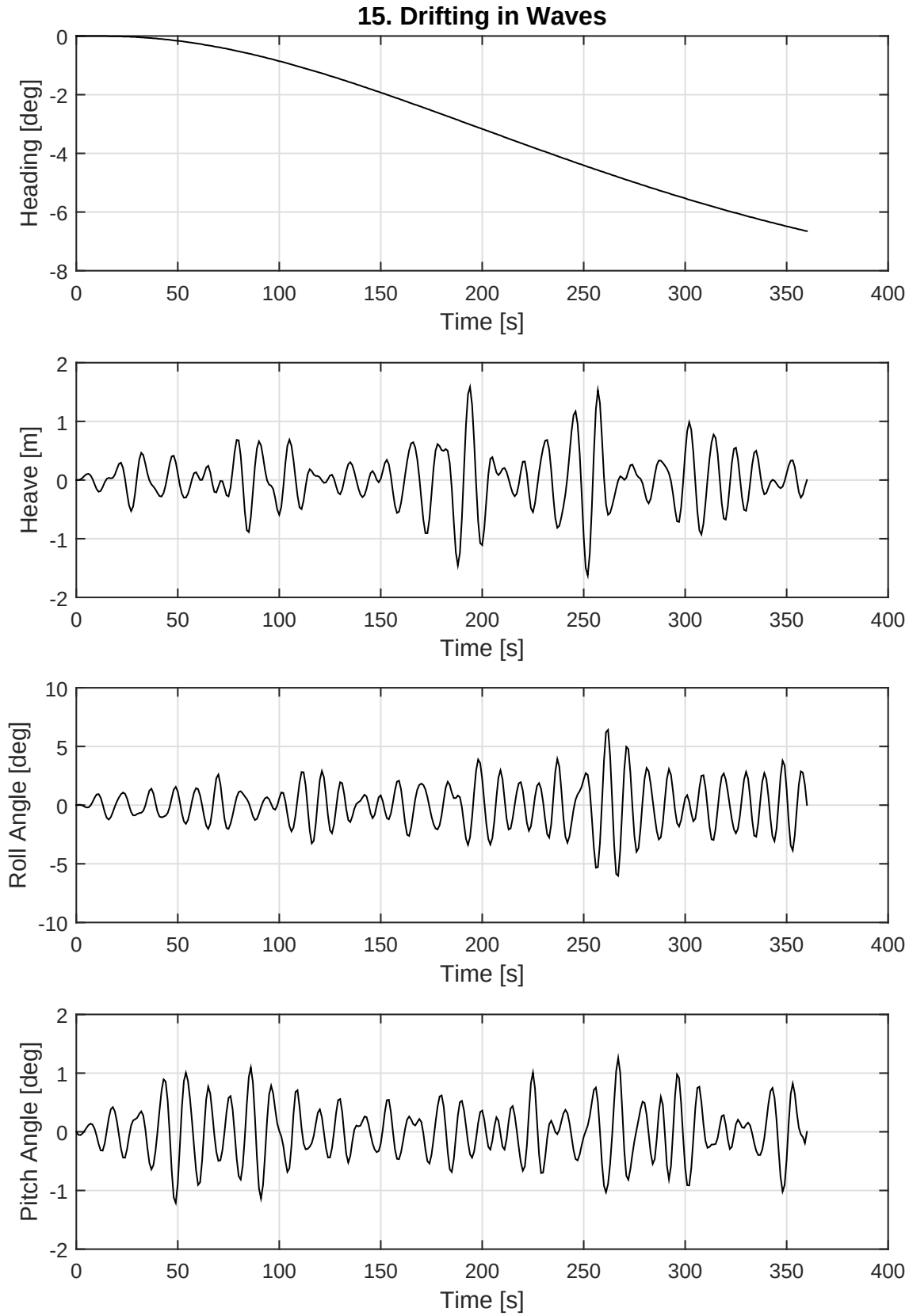
Results and Equilibrium Values

Longitudinal Speed	: -0.3 knots
Transverse Speed	: 0.4 m/s
Maximum Roll Angle	: 6.4 deg








15. Drifting in Waves
Heading [deg]
Time [s]
Heave [m]
Time [s]
Roll Angle [deg]
Time [s]
Pitch Angle [deg]
Time [s]

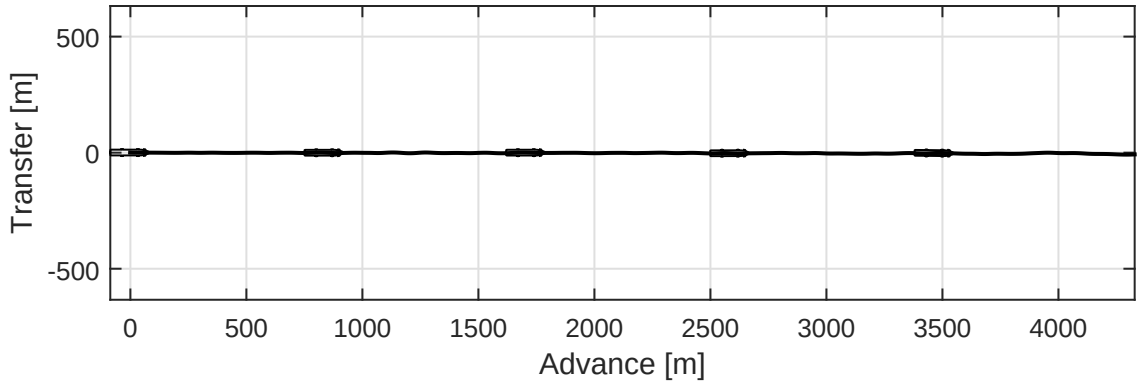
16. Sailing with Autopilot in Waves

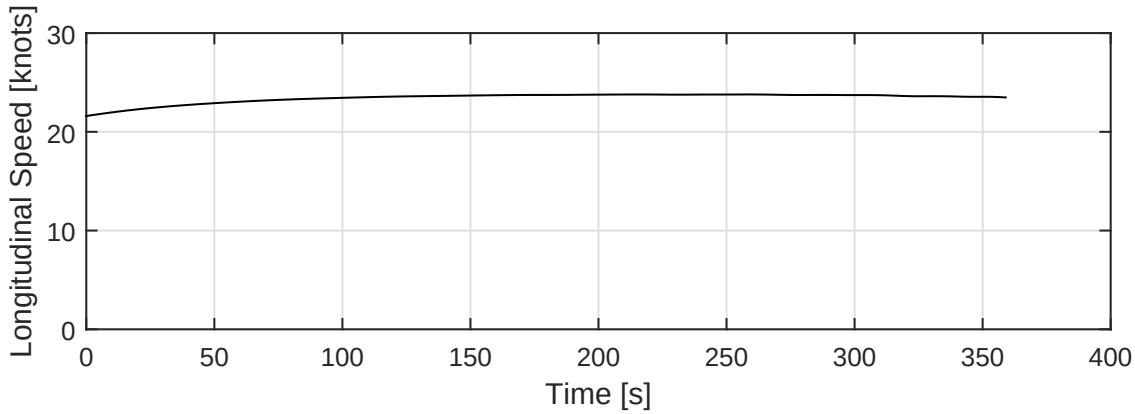
Initial Conditions and Controls

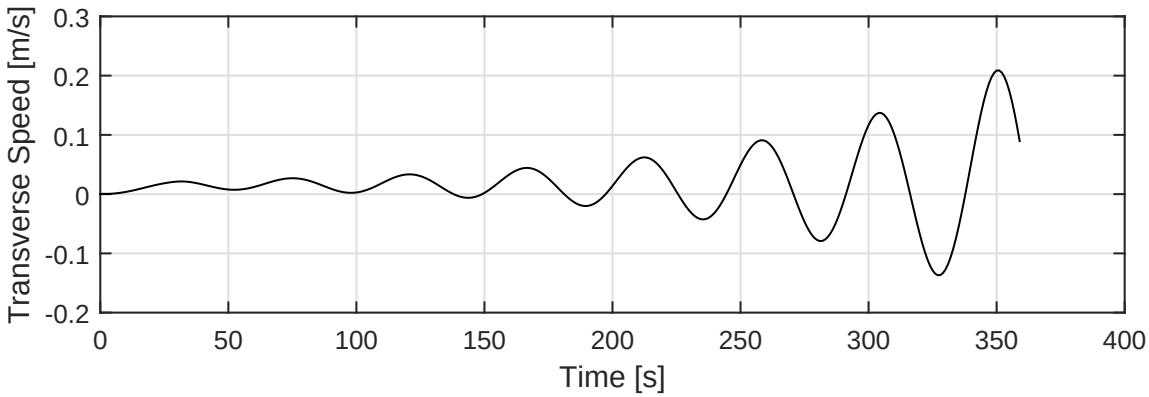
Water depth	: h/T = 1
Wave height (Hs)	: 3 m
Wave period (Tp)	: 9.1 s
Wave direction	: 90 deg

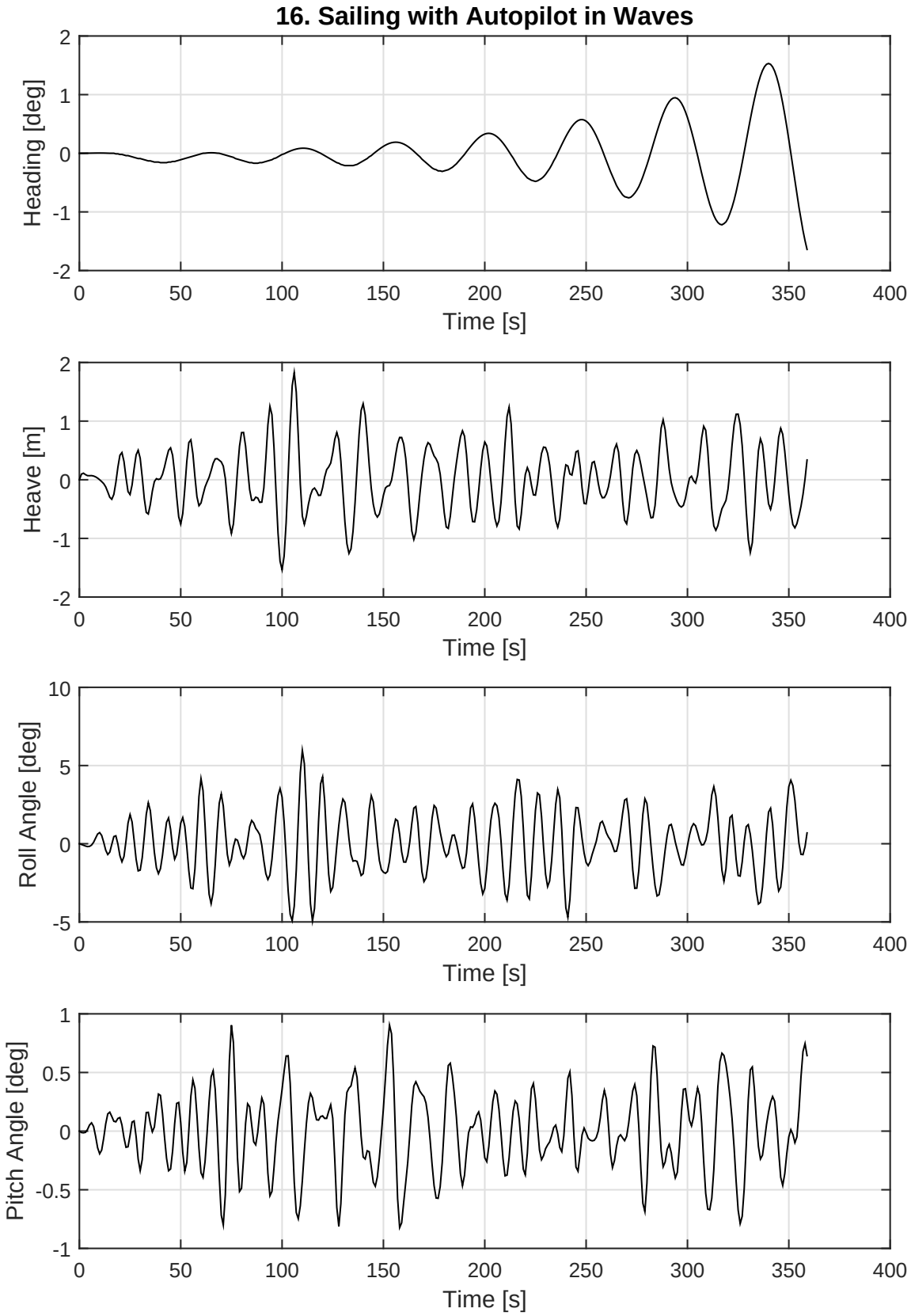
Results and Equilibrium Values

Longitudinal Speed	: 23.5 knots
Transverse Speed	: 0.1 m/s
Maximum Roll Angle	: 6.0 deg








16. Sailing with Autopilot in Waves
Heading [deg]
Time [s]
Heave [m]
Time [s]
Roll Angle [deg]
Time [s]
Pitch Angle [deg]
Time [s]