DUN LAOGHAIRE CRUISE TERMINAL
DUN LAOGHAIRE, IRELAND

NAVIGATIONAL ANALYSIS

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1. INTRODUCTION

This report presents a navigational analysis for the conceptual design of a new cruise terminal in Dun Laoghaire, Ireland. The purpose of this report is to provide planning stage validation of the proposed layouts from a navigational standpoint and offer any additional recommendations to the planned configurations and operations.

2. FACILITY AND CONCEPT BACKGROUND

2.1 OVERVIEW

Dun Laoghaire lies on the east coast of Ireland, south of Dublin. It is a prosperous town with a large harbour enclosed by two breakwaters dating back to the mid-1800s.

Figure 2-1: Overview of Project Location

The harbour was originally conceived as a port of asylum (refuge) within Dublin Bay, but has provided a point of access for ferries and the mail-boat service. Present ferry operations are currently restricted to limited seasonal Stena HSS connection to Holyhead. When implemented in 1995, this offered three sailings per day. However, the vessel is expensive to run with high fuel costs even when operating at reduced speeds. The service has been curtailed and now runs as a summer-only single daily sailing. It is understood that operations are unlikely to continue beyond 2015.

In addition to the ferry, the harbour hosts the operations of Irish Lights (the navigation authority), an 800-berth commercial marina, a number of swinging moorings and a selection of yacht clubs.

The Dun Laoghaire Harbour Company is a commercial state-owned harbour authority.

Figure 2-2: Satellite image of Dun Laoghaire Harbour

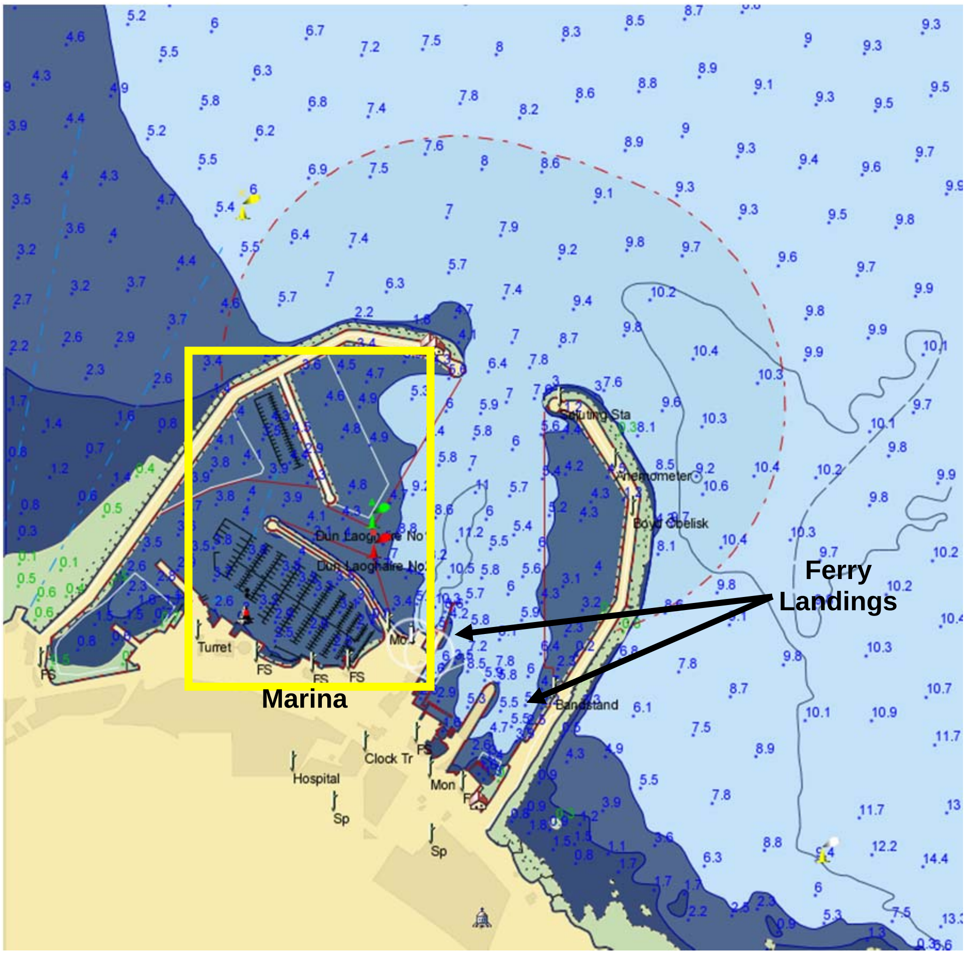


Figure 2-3: Nautical Chart Features of Dun Laoghaire Harbour

2.2 PRELIMINARY CHANNEL LAYOUT

Channel dimensions and proposed dredging were determined using the design vessel and evaluation criteria identified in the previous report '*Cruise Terminal Design Criteria*' issued by Moffatt and Nichol December 4, 2013. This report identified a Freedom Class cruise ship as the desired design vessel and utilised PIANC channel guidelines for sizing appropriate channel widths and depths of 120m and 10.5m (below Chart Datum), respectively.

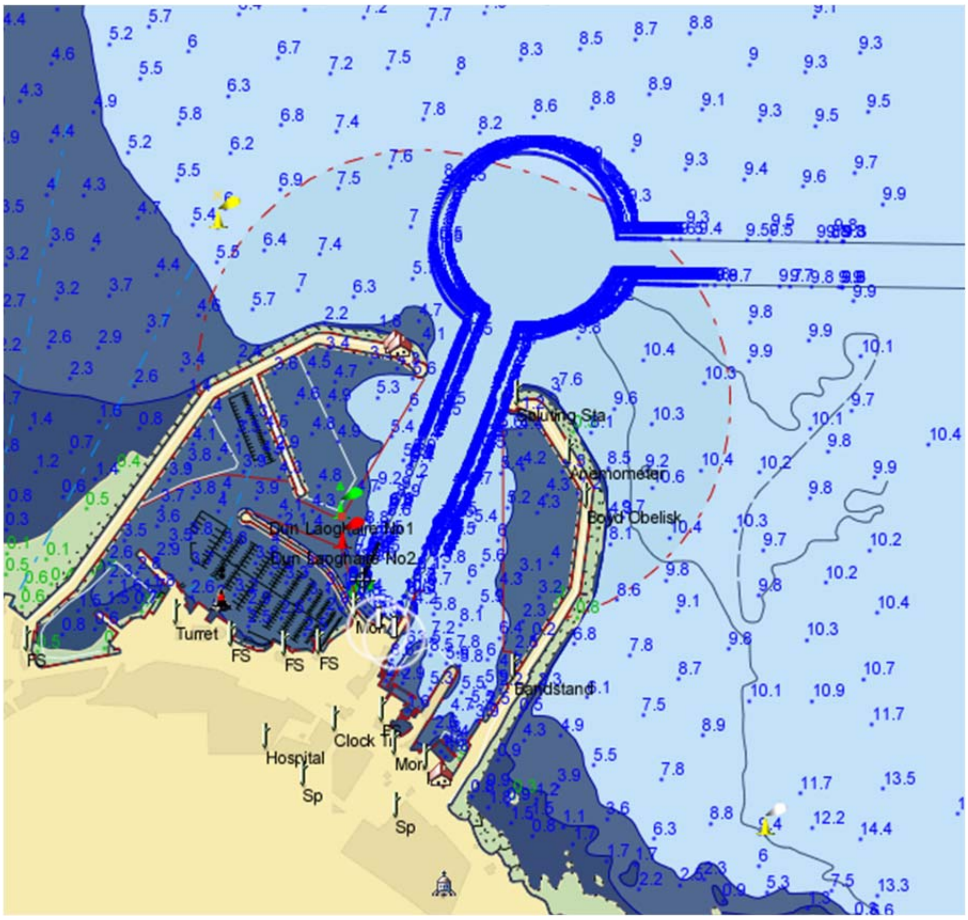


Figure 2-4: Modified Nautical Chart of Dun Laoghaire Harbour

Figure 2-4 displays the preliminary layout used in this navigational analysis. The turning basin was sized with a diameter of 500m and dredge slopes were assumed at 3:1. It should be noted that these designs are for feasibility planning stages only and meant only to assess the viability of this project at an initial stage. Reduction in bank steepness to 5:1 should reduce bank induced forces on the vessel. However, these forces were observed to be minimal for 3:1 in the simulations so little to no effect should arise from reduction in the bank profile.

2.3 SITE BATHYMETRY

Bathymetry in the project area was developed from digitized nautical charts and a survey conducted by HSL from the 23rd to the 25th of November, 2013.

3. VESSEL MANOEUVRING STUDY

The concept layout of the channel, bends, and turning basin is based on PIANC (1995) recommendations on approach channel design. The following numerical simulation study evaluates the manoeuvrability of the design vessels into the harbour under a limited number of environmental conditions. The manoeuvres are evaluated for safety by examining swept path, clearance to structures/vessels, adequacy of propulsion, and difficulty.

3.1 VESSEL MANOEUVRING SIMULATIONS

The vessel simulations contained herein were conducted using the navigation simulation software Navi Trainer Pro 5000 (NTPro) developed by Transas in St. Petersburg, Russia. The NTPro software performs detailed computer-based simulation of the manoeuvres required for the design vessel to safely transit the route within the confines of the navigation channel.

NTPro is a vessel manoeuvring software used to assess complex manoeuvres and associated vessel motions in a variety of environments including shallow water manoeuvring. The software is the same software framework utilised in full mission bridge simulators across the globe. Features of the model include full six degree of freedom vessel hydrodynamics, three dimensional harbour area representation, explicit tug model behaviour, vessel response to wind, wave currents, bathymetry, vessel-structure and vessel-vessel interaction. Vessels are discretized to allow for force shadowing and differentiation along the ship. Ship models used in the simulators are developed and verified with data from basin tests and real world collection schemes.

These simulations are used by engineers as a screening tool to identify the most critical environmental conditions, test channel layouts and provide guidance on harbour manoeuvres. For the proposed design vessels, a matrix was developed of simulated approaches and dockings under various wind conditions.

3.2 DESIGN VESSELS

From a navigational and manoeuvring standpoint, the largest anticipated vessels calling at the different berths will control the evaluation of the proposed channel and basin design. This study is concerned with the feasibility and efficiency of cruise ship manoeuvres in the proposed access channels and turning basin. Two vessels were considered in this study: a large 350m length overall (LOA) non-Azipod (fixed propeller) cruise ship and a smaller 300m LOA two Azipod cruise ship, both from the database of Transas ship models. The *Freedom* class falls in between the two model vessels.

Hydrodynamic models developed and tested of the Freedom class cruise ships are property of Royal Caribbean and restricted without their express permission. Ships selected for the simulations were chosen based on available validated models and their ability to bracket the range of vessels considered in the basis of design. At this time, without specific involvement of Royal Caribbean, the model vessel is not available.

While the fixed propeller cruise ship is at the limit of manoeuvrability with the existing alignment, simulations with this vessel serve to illustrate potential concerns with this class of ship with regards to the proposed project. Additionally, design of the channel for one particular class (especially one such as Freedom with top of the line power/control) may limit the long term use of the terminal should another cruise line with different characteristics call at the port. The conservative approach taken for this preliminary planning study is to provide a channel that can accommodate a range of ships.

3.2.1 Modelled Fixed Propeller Cruise Ship

Ship particulars for the fixed propeller cruise ship used in the simulations were based on a verified model from the Transas database. Table 3-1 and

Table 3-2 list the ship particulars for this model. For reference, design vessel characteristics presented '*Cruise Terminal Design Criteria*' issued by Moffatt and Nichol December 4, 2013 are presented in Table 3-3.

The parameters below represent similar propulsive characteristics and dimensions of Disney Dream class liners and other large fixed propeller ships and provide a means of assessing how these vessel types will perform at the proposed terminal. All simulations of the cruise ship utilised no assistance from tugs.

Without access to the validated Freedom class ship model, a direct one-to-one validation of the proposed project was not possible. This study instead focused on using other available validated models to investigate the proposed project and deliver initial concerns and modifications.

In particular, the availability of more thruster power on the Freedom class ships when compared to the 350m ship model used in the study will provide more manoeuvrability (similar to the 300m Azipod model) of the ship when the two are compared.

There are differences in displacement between the Freedom and 350m vessels which affect the outcome of the simulations, albeit not enough to change the conclusions. While the higher displacement of the Freedom class ships will reduce some manoeuvrability of the vessels, the additional directional stability combined with significant benefits in available thrust from the Azipods and bow thrusters permit the Freedom vessel to make the transit efficiently and within the proposed channel limits.

Table 3-1: Modelled Fixed Propeller Cruise Ship Particulars

Particular	350 m Cruise Ship
Length Overall	350 m
Beam	48 m
Total Height	70.5 m
Draught Forward	8.5 m
Draught After	8.5 m
Displacement	71222 tonnes
Deadweight Tonnage	11020 tonnes
Engine Type	Slow Speed Diesel
Power	2 x 26200 kW
Number of Propellers	2
Number of Rudders	2
Bow Thruster	3 x 3000 kW
Stern Thruster	2 x 2000 kW

Table 3-2: Engine Telegraph Settings for the Modelled Fixed Propeller Cruise Ship

Telegraph Setting	RPM
Full Sea Ahead	140
Full Ahead	90
Half Ahead	60
Slow Ahead	40.1
Dead Slow Ahead	20
Dead Slow Astern	-20.3
Slow Astern	-40.3
Half Astern	-60.5
Full Astern	-90.6

Table 3-3: Basis of Design VLCC Particulars

Particular	VLCC (90%)
Length Overall	338.9 m
Length Between Perpendiculars (LBP)	303.3 m
Beam	38.6 m
Total Depth	63.7 m
Design Draught	8.5 m
Engine Type	Diesel-Electric
Power	3 x 14 MW ABB Azipods (two azimuthing, one fixed centreline)
Bow Thruster	4 x 3300 kW

3.2.2 Modelled Azipod Cruise Ship

Ship particulars for the Azipod cruise ship model were also based on a verified model from the Transas database (Table 3-4 and Table 3-5).

Again, these values represent the typical characteristic dimensions of this vessel class of this size and yield a satisfactory method for evaluating the manoeuvring performance of this vessel class in the proposed terminal access channels and turning basin. Simulations involving these models utilised no tug assistance.

Table 3-4: Modelled Azipod Cruise Ship Particulars

Particular	300 m Cruise Ship
Length Overall	294 m
Beam	37.9 m
Total Height	59.2 m
Draught Forward	8 m
Draught After	8 m
Displacement	44000 tonnes
Engine Type	Diesel-Electric
Power	2 x 17600 kW
Number of Propellers	2
Bow Thruster	3 x 2360 kW

Table 3-5: Engine Telegraph Settings for the Modelled Azipod Cruise Ship

Telegraph Setting	RPM
"100%"	140
"80%"	120
"60%"	89
"40%"	59
"20%"	28
"-20%"	-28
"-40%"	-59
"-60%"	-89
"-80%"	-116
"-100%"	-116

3.3 METOCEAN CONDITIONS

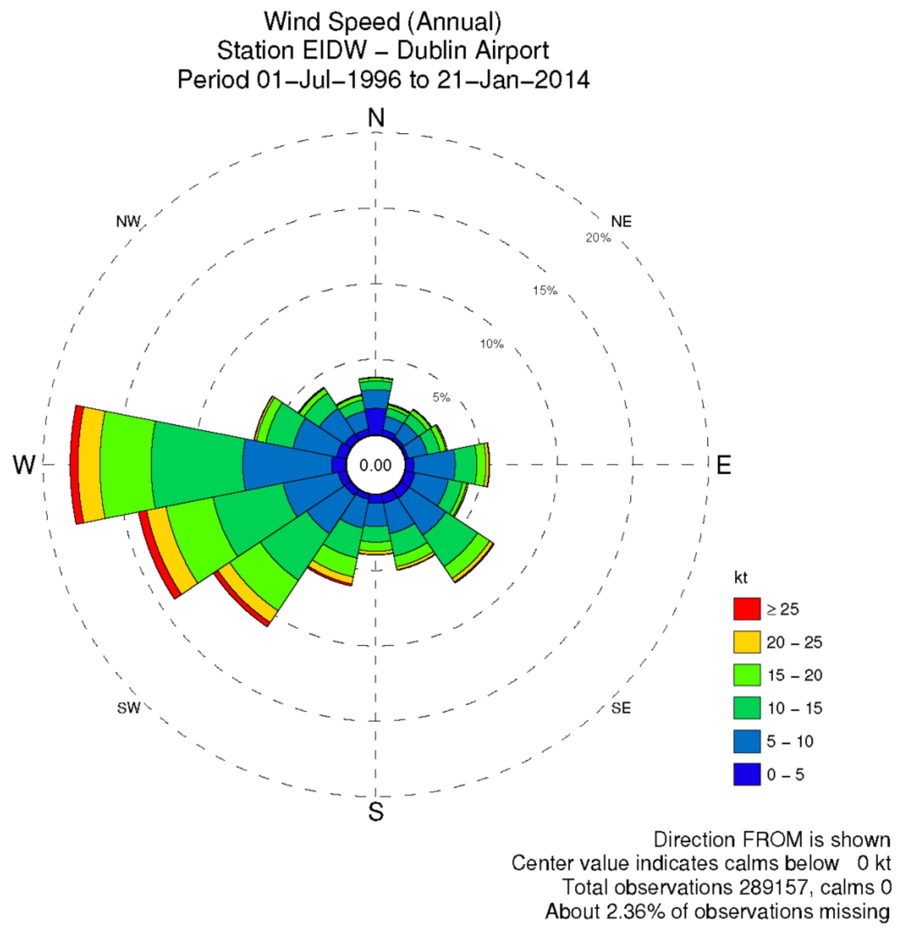
All metocean conditions considered in this report have not been analysed in detail and were developed only to serve in the initial planning stages of this project. Further metocean data collection, analysis and modelling is recommended before continuing further assessments.

3.3.1 Simulated Wind Fields

Wind data was collected from METAR data recorded at the Dublin International Airport (ID: EIDW) from July 1996 to present date (Figure 3-1). Data analysis indicated a prevalent wind direction coming from the west, southwest, and southerly directions (Figure 3-2). Seasonal analysis demonstrated little variability in the directionality in the wind but did indicate increased wind speeds during the winter months and slightly milder winds during the summer season.

This data also indicates that speeds of 25, 20 and 15 knots (hourly average) have a probability of exceedance of about 1%, 7%, and 23%, respectively (Figure 3-3). With their large windage areas, cruise ships are highly sensitive to the effects of wind and slow speed manoeuvres of these vessels are typically restricted to wind speeds of 25 knots or less, depending on their available propulsion capabilities. As a preliminary navigational assessment and verification of the initial channel design, a speed of 15 knots was simulated in the navigational analyses, with winds of 25 knots being tested only in those simulations utilising vessel equipped with Azipod propulsion systems. Wind directions were modelled from the west, southwest, and south (Table 3-6). It was assumed that for hourly winds greater than 25 knots, vessels would not approach the terminal and would wait for lighter air.

Figure 3-1: Dublin International Airport Location



Percentage of Occurrence

Wind Speed, kt	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total
Total	3.80	2.13	2.45	2.83	5.54	4.24	7.42	5.13	3.98	6.18	10.91	14.00	18.21	6.22	4.18	2.76	100.00
≥ 25										0.14	0.34	0.55	0.52				1.89
20 – 25					0.21		0.28	0.21	0.21	0.48	0.94	1.31	1.45	0.15			5.72
15 – 20	0.19	0.21	0.32	0.38	0.59	0.27	0.96	0.72	0.61	1.28	2.43	3.17	3.39	0.62	0.38	0.30	15.84
10 – 15	0.57	0.56	0.73	0.87	1.43	0.95	2.51	1.52	1.04	2.01	3.70	4.73	6.06	1.84	1.22	0.75	30.52
5 – 10	1.24	0.91	1.13	1.29	2.73	2.26	2.94	2.05	1.53	1.94	3.03	3.71	5.89	2.95	2.01	1.22	36.84
0 – 5	1.74	0.36	0.21	0.17	0.52	0.64	0.65	0.59	0.55	0.34	0.46	0.53	0.90	0.63	0.49	0.41	9.20

Figure 3-2: Annual Wind Rose at Dublin International Airport

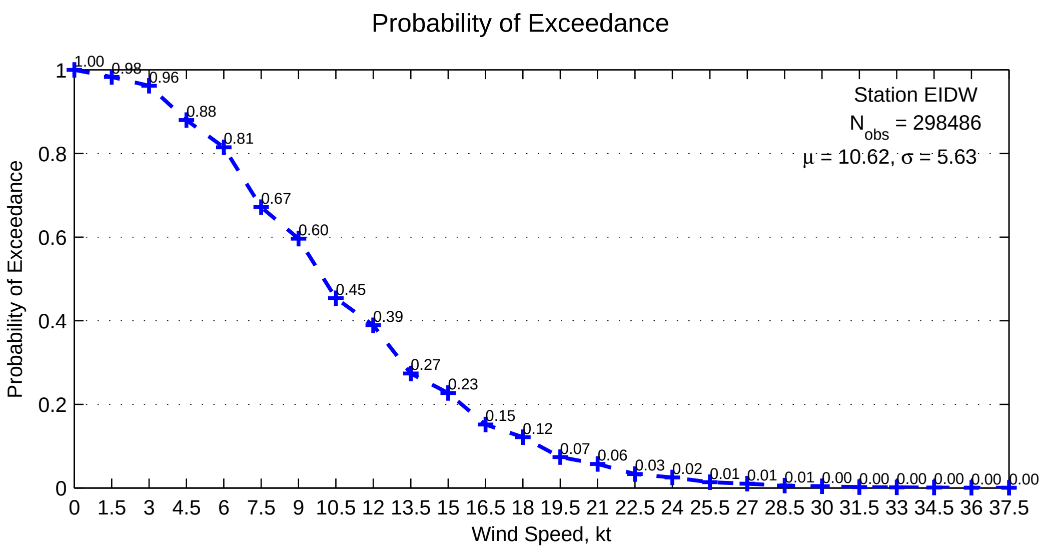


Figure 3-3: Wind Speed Probability of Exceedance

Table 3-6: Simulated Wind Fields

Wind ID	Hourly Wind Speed, kts	Wind Direction, (Degrees N, from)
W	15	270
SW	15	225
S	15	180

3.3.2 Simulated Current Fields

No current data was collected as part of this study effort. Currents were not applied to the navigation simulations. Currents in the vicinity should be surveyed and assessed as the design moves forward.

3.3.3 Simulated Wave Fields

While extreme event data has been reviewed within previous EIA data, the modelling has been undertaken utilising derived background conditions. Waves were modelled as a Pierson-Moskowitz spectrum with a significant wave height of 0.4 metres from the northwest. The Pierson-Moskowitz spectrum is a mathematical model developed to create an empirical relationship defining the distribution of wave energy with frequency. This spectrum is often used in hydrodynamic models to generate a random wave field of a specified spectrum based on a peak wave period, significant height and shape parameter.

These conditions were established using measurements listed on the Dun Laoghaire harbour website. Further studies would warrant wave measurement collection and modelling to establish more concrete ambient and more energetic operational conditions for these manoeuvres.

3.3.4 Model Bathymetry and Layout

Bathymetry, harbour layout, and navigational aid locations used in the simulations were taken from up to date nautical charts and surveys of the area. Only one preliminary dredging option was tested during this analysis which utilised 120m channel widths and a 500m idealised turning basin diameter. Dredge slopes were assumed at a 3:1 slope and were day-lighted to the existing bathymetric surface. Channels were aligned with existing traffic patterns into and out of the harbour.

3.4 BASIS OF MANOEUVRES

3.4.1 Existing Harbour Traffic

Existing vessel traffic in the harbour was studied to provide a representation on the effect proposed cruise ship operations would have on daily traffic in Dun Laoghaire.

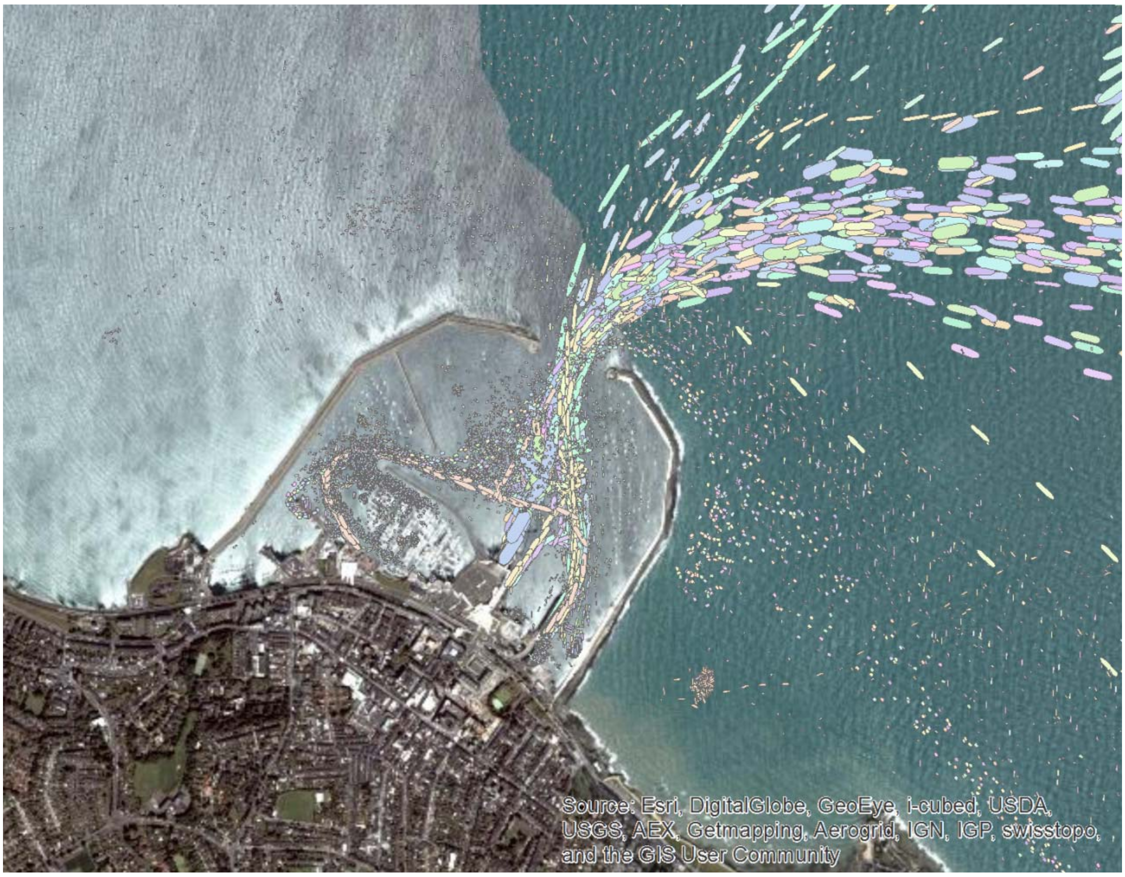


Figure 3-4: Dun Laoghaire Vessel Traffic July 2013 – January 2014

Commercial Ferry traffic frequents the main ferry landing adjacent to the proposed cruise terminal location as well as the pier in the south-eastern corner of the harbour. Additionally, there is heavy pleasure vessel traffic to and from the marinas in the western half of the harbour. Figure 3-4 which demonstrates the actual ship shape and heading at each received position for commercial vessels whereas Figure 3-5 shows vessel paths in Dun Laoghaire where yellow lines indicate pleasure vessels and red lines indicate commercial traffic. The vessel path plot in Figure 3-5 represents the temporal collection of vessel broadcast information. It is noted that the temporal spacing of these signatures is long enough that it will appear as if the vessel is traversing across a land based boundary. This is due to the fact that the positions recorded with a long time interval such that the straight line between successive points has, for some vessels, indicated a track that can be drawn partially (or totally) over land.

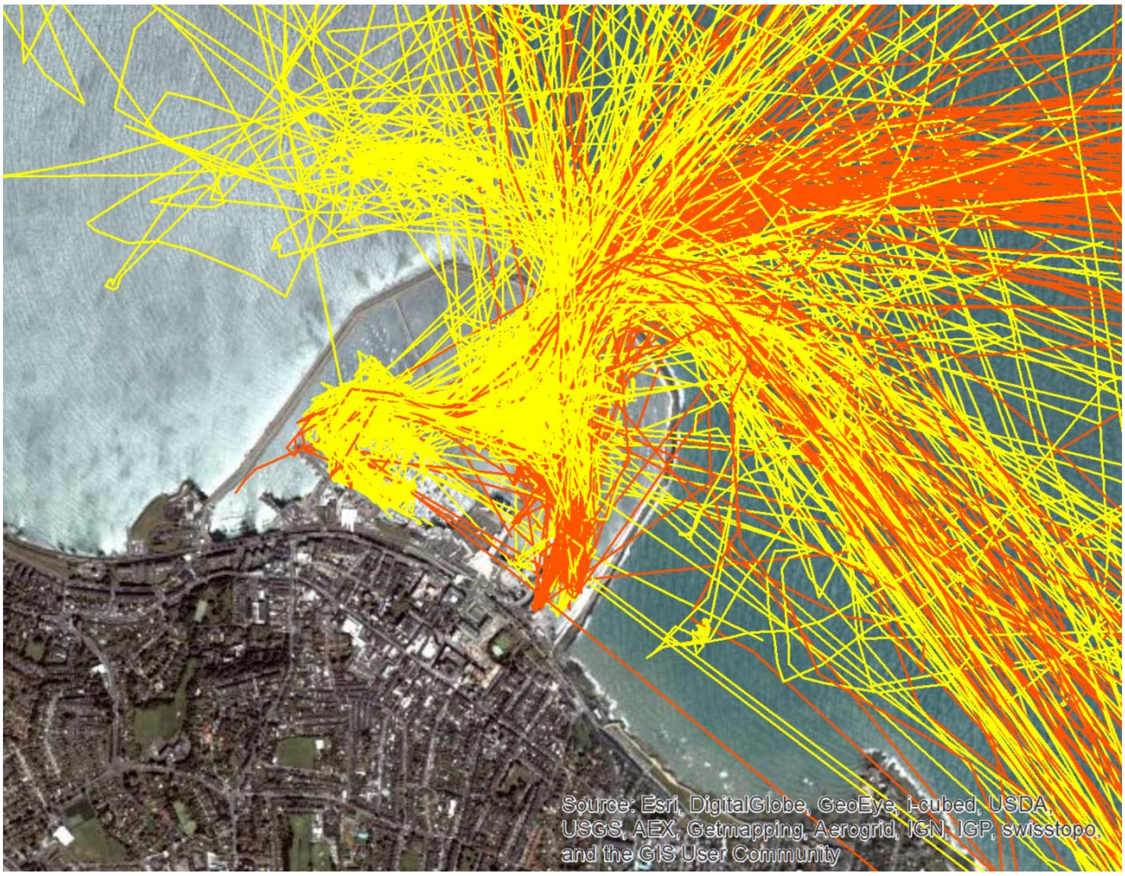


Figure 3-5: Vessel Paths in Dun Laoghaire Harbour (July 2013 – January 2014)

3.4.2 Fixed Propeller Cruise Ship Inbound Manoeuvres

Manoeuvres involving the fixed propeller cruise ship simulations were based off of real world manoeuvres of similarly powered and dimensioned ships. Vessel speeds, accelerations, and rates of turn were calculated, studied and used as the basis of the simulations. Background data for ship manoeuvres include tracking for the inbound berthing manoeuvres of the *Norwegian Epic* in Naples (Figure 3-6) and the Royal Princess in Piraeus. Appendix B has example plots and graphs of these observed manoeuvres. It is not assumed that the presented manoeuvres represent the best or only like manoeuvres to those anticipated at Dun Laoghaire; these manoeuvres were selected as representative and similar transits from which to base an engineering analysis of the proposed project upon. The selected manoeuvres illustrate a typical manoeuvre for similarly equipped vessel, which slowly turn, and back to berth.

Figure 3-6: *Norwegian Epic* Inbound Manoeuvre to Naples

3.4.3 Azipod Cruise Ship Inbound Manoeuvres

Similar to the manoeuvres for the fixed propeller cruise ship, vessel movements of Azipod equipped cruise ships were studied and used as the basis for cruise ship movements into and out of the proposed terminal in Dun Laoghaire; In this case, manoeuvres of freedom class cruise ships were examined. Vessel speeds, accelerations, and rates of turn were calculated, studies and used as the basis of the simulations. Figure 3-7 presents an example inbound manoeuvre of the *Independence of the Seas* in St. Maarten in December of 2013.

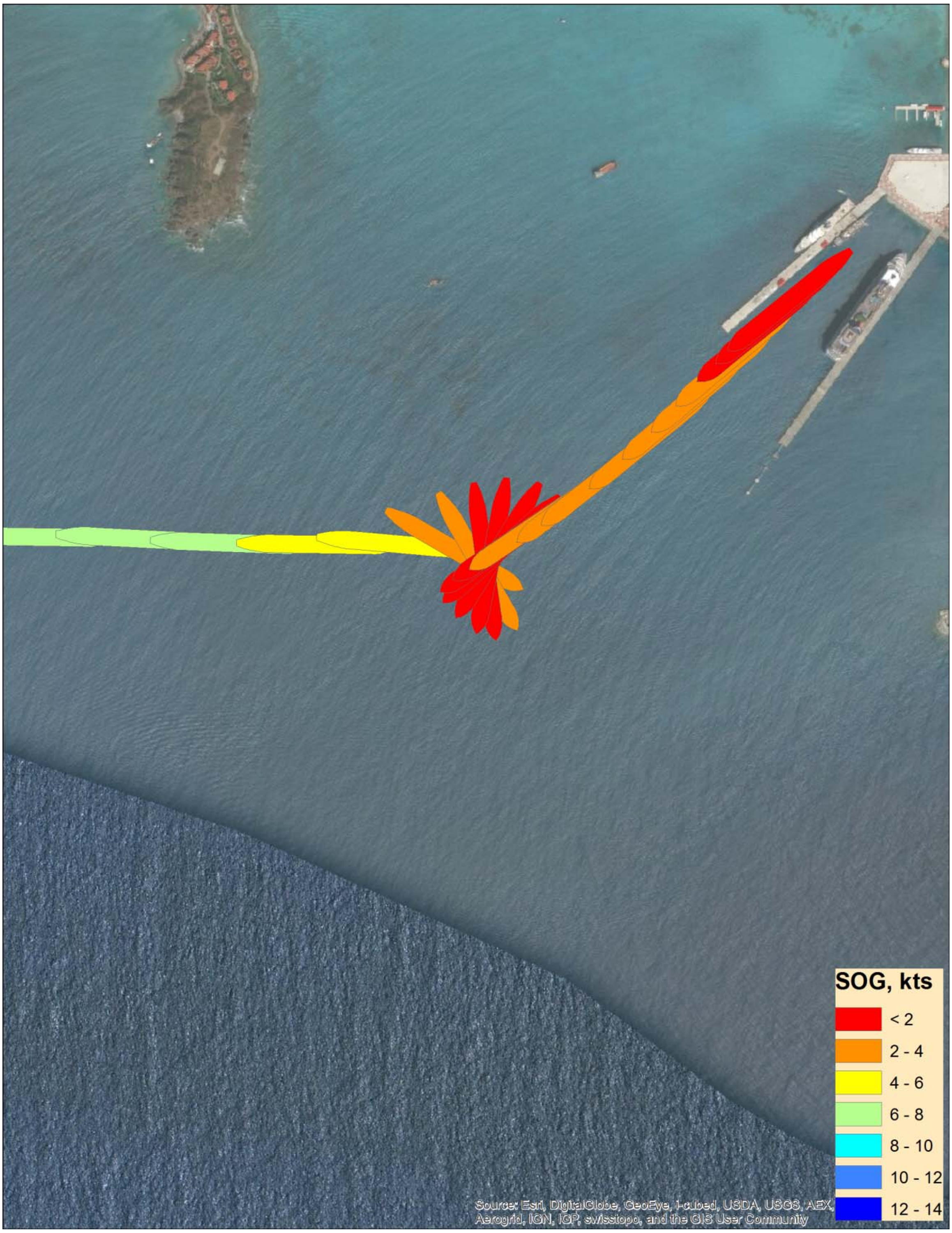


Figure 3-7: *Independence of the Seas* Inbound Manoeuvre to St. Maarten.

3.5 TESTING MATRIX

The above conditions led to the development of a testing matrix employed to evaluate the proposed project viability from a navigational standpoint. Table 3-7 provides the matrix containing simulation parameters for the navigational analysis.

The common parameters evaluate inbound transits with 3 incident wind directions. Initial simulations for each condition attempted to bring the vessel in stern-first to berth; wind and vessel propulsion scenarios prohibiting such manoeuvres were repeated and simulated bringing the vessel bow-in. Outbound manoeuvres were simulated only for the non-Azipod propulsion scenarios in which a bow-out and bow-in departure were simulated under the worst case wind conditions previously simulated (worst case was winds from the west for the bow-out departure and winds from the southwest for the bow-in departure). Outbound manoeuvres for the Azipod equipped vessels were not evaluated as these ships were observed to have enough power to depart sufficiently.

Table 3-7: Simulation Matrix

Run	Vessel	Manoeuvre	Wind Speed, knots	Wind Direction, From
1	350m Cruise Ship	Inbound	5	W
2		Inbound	15	W
3		Inbound	15	SW
4		Inbound	15	S
5		Outbound, bow-first	15	W
6		Outbound, stern-first	15	SW
7	300m Cruise Ship	Inbound	5	W
8		Inbound	15	W
9		Inbound	15	SW
10		Inbound	15	S
11		Inbound	25	W

3.6 EVALUATION CRITERIA

Results of the model simulations were evaluated based on horizontal plane vessel behaviour and the usage of available input forces acting on the ship (i.e. rudder, engine and thruster usage) as well as safe and practical limits for underkeel clearance (UKC). Simulations with controlled drift angles (desired to be less than 15 degrees from the intended heading), travelled positions within a beams width of the planned track and total swept paths representing less than 70% of the total available manoeuvring areas (channel and turning basin evaluated separately) were considered acceptable manoeuvres with respect to the vessel's positions with respect to the horizontal plane. Typical manoeuvres are deemed acceptable if the combined exceedance of rudder angle and engine rpm, as a percentage of 20 degrees of rudder and half ahead engine settings, respectively, occurred less than

5-10% of the total duration of the manoeuvre; however, as the manoeuvres considered in this report are primarily berthing/unberthing manoeuvres (in which the rudder is essentially ineffective), this criteria is ignored. Furthermore, complicated and/or dangerous manoeuvres would be evaluated as unacceptable. Manoeuvres requiring sustained thruster and/or engine telegraph settings exceeding 50% of available power are considered operationally marginal and are not recommended.

4. SIMULATION RESULTS

The following sections describe results of the simulations for the tested runs. Each section provides a summary of the tested manoeuvres and provides typical manoeuvre paths. It should be reiterated that the efforts put forth in this analysis are only to assess the viability of the proposed project from an engineering standpoint with regard to navigation; because of this, simulation plots for vessel force input (rudder, engine telegraph settings, thruster usage, etc.) should be considered only in the realms of available forces acting on the modelled vessel. Output from the model is useful for planning stage analysis and initial determination of potential problem areas or conditions to be further evaluated or verified in full mission simulations with pilots at the conning station.

Figures describing the typical manoeuvre were simulated with applied environmental conditions and were selected for visual reference. All mention of vessel speed herein is referenced to speed through the water. The following sections will briefly describe the usage of main propulsion, rudder (or pod) angle, thruster usage, and wind forces/moments, channel clearances, bank forces/moments, and UKC.

4.1 FIXED PROPULSION CRUISE SHIP

Figure 4-1: Visual Channel Output of the Fixed Propeller Cruise Ship Approaching Dun Laoghaire Harbour

4.1.1 Run 1 – Inbound Mild Conditions

Description:

The inbound manoeuvre brings the ship along the proposed channel's centreline and begins a stern swing to port in anticipation for alignment with the channel directly into the harbour. Thrusters and asynchronous use of the rudders and main propulsion system are used to start and check the swing of the ship. When backing down the channel, bow and stern thrusters are used for heading adjustments and the approach to the proposed berth.

Main Propulsion:

With mild conditions and ample UKC, excessive use of propulsion to maintain headway, sternway and the swing are limited to 40 rpm forward and 60 rpm astern.

Rudder:

Rudder usage is kept in reasonable ranges and is only used asynchronously to swing the stern to port in the initial turn.

Thruster:

Thruster usage is only used beyond 50% of total power for short bursts.

Wind force and moment:

Wind action on the vessel is negligible (< 1 tonne transversely) due to the low 5 knot ambient winds.

Clearances:

The vessel's initial stern swing to port encroaches on the south-eastern intersection of the approach channel and turning basin. All other clearances are acceptable.

Bank force and moment:

Ample clearance of the vessel hull to the channel banks prevent any significant bank induced forces; only a small spike around 2 tonnes is seen when the stern is swinging to port.

Depth:

UKC during the simulation is never less than 2 metres.

Overall:

This preliminary manoeuvre yields forces well within the controllable limits of the vessel and provides channel clearances that are deemed acceptable.

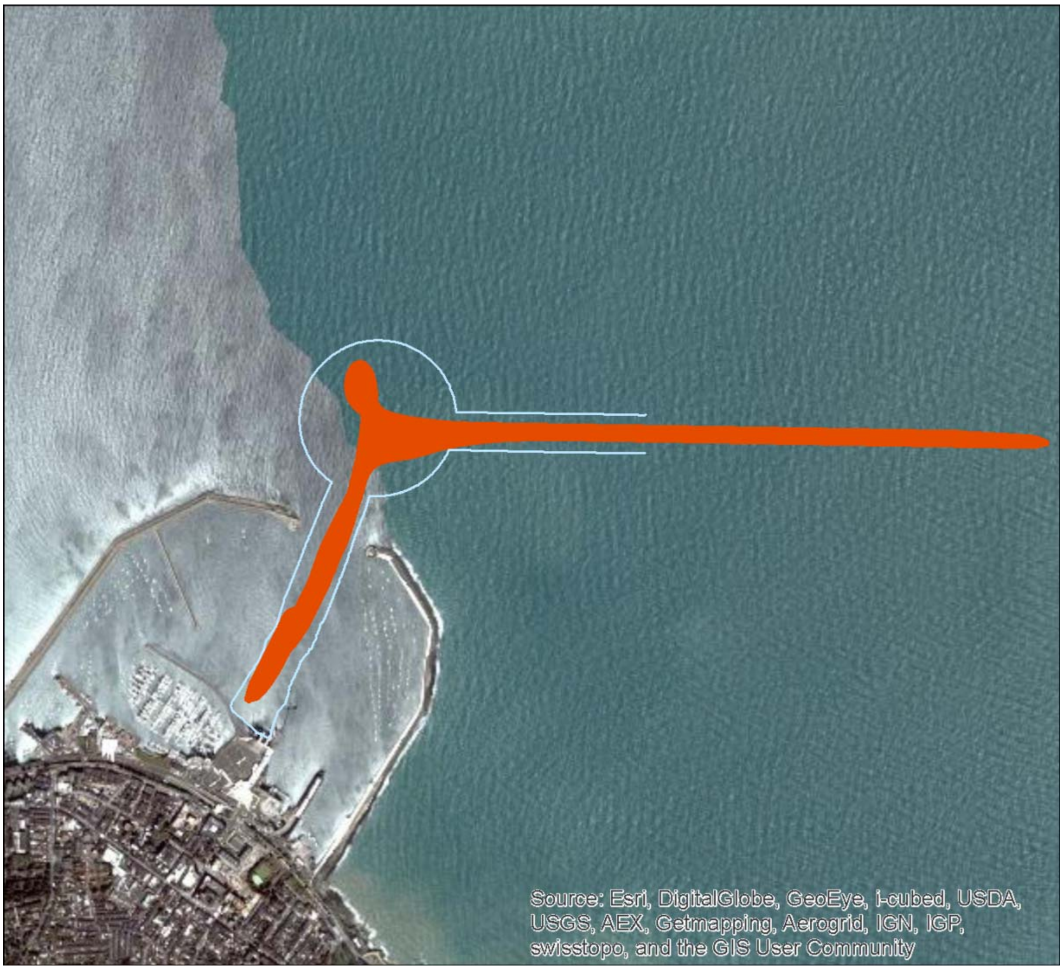


Figure 4-2: Swept Path Plot for Run 1

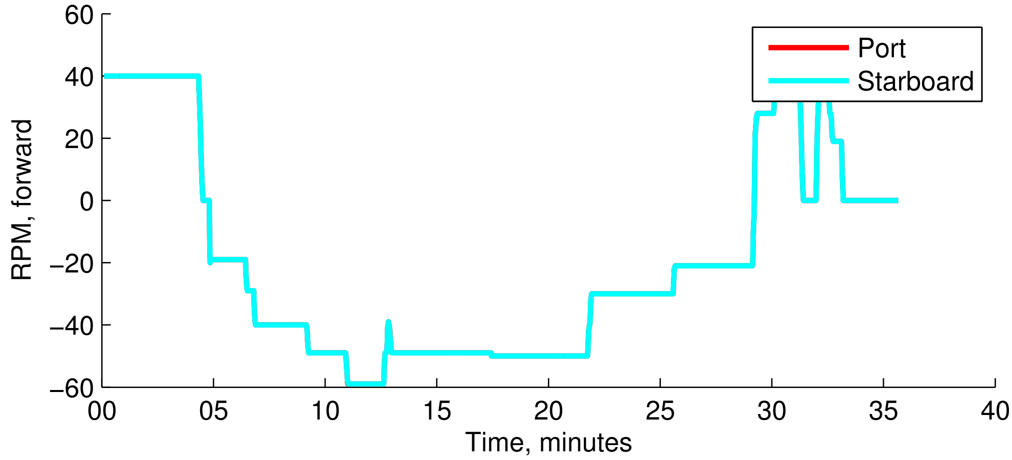


Figure 4-3: RPM Plot for Run 1

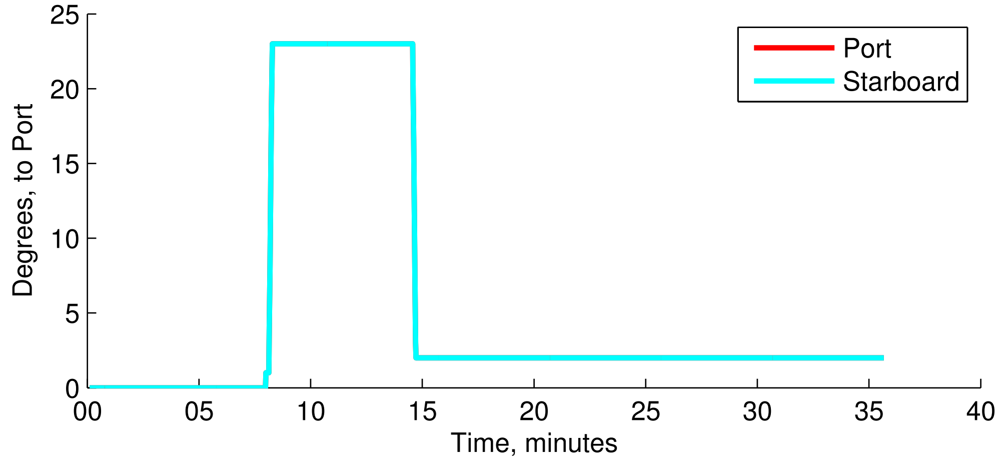


Figure 4-4: Rudder Plot for Run 1

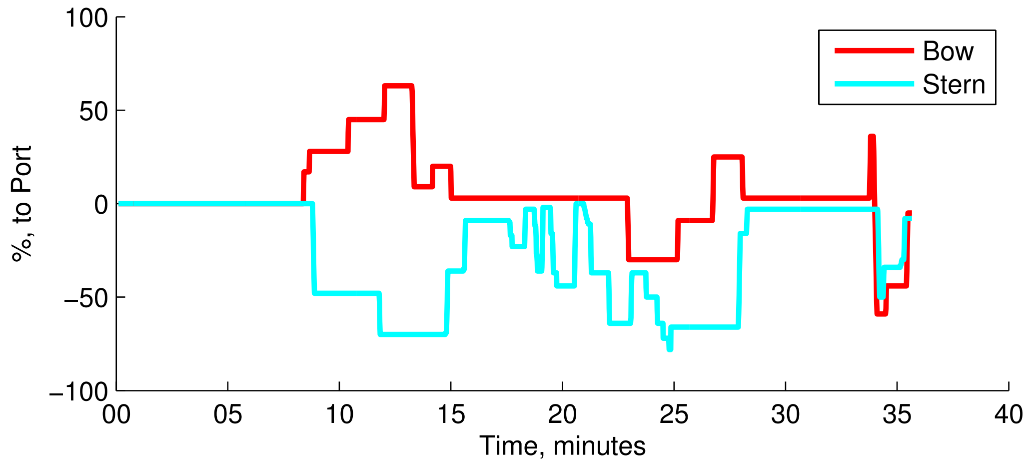


Figure 4-5: Thruster Usage Plot for Run 1

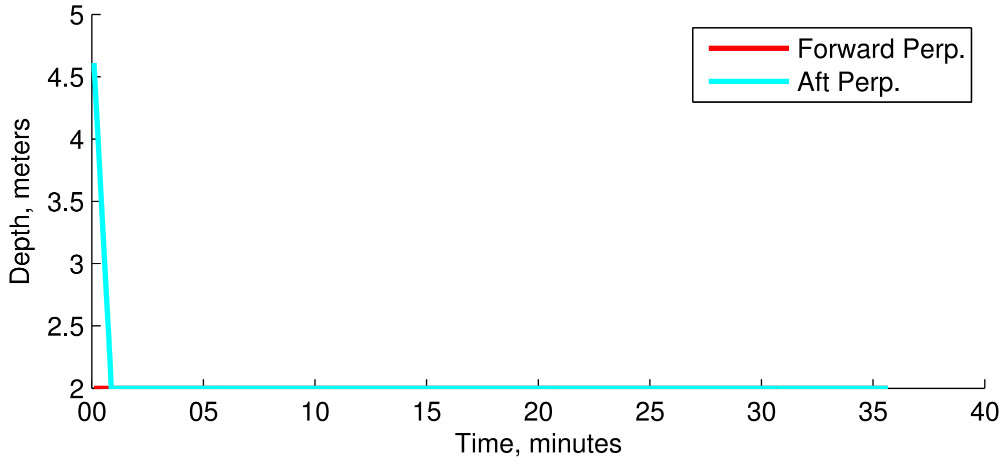


Figure 4-6: UKC Plot for Run 1

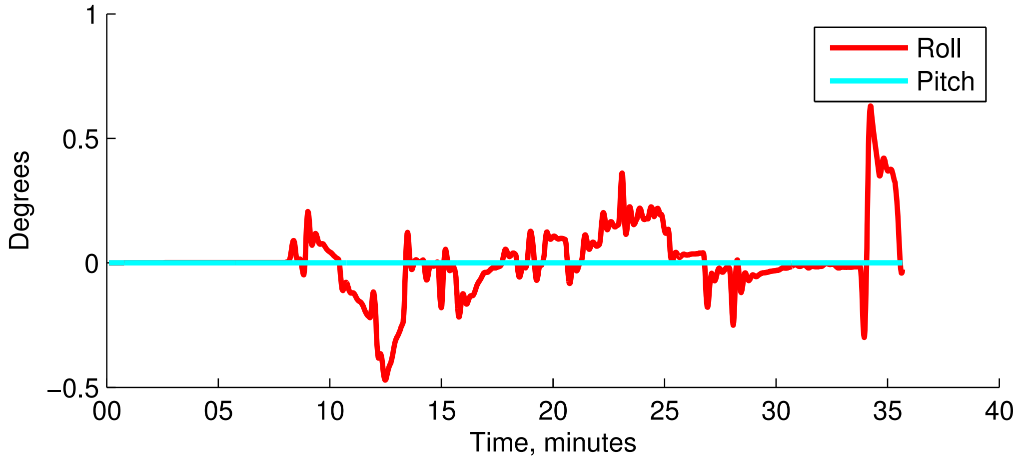


Figure 4-7: Roll and Pitch Plot for Run 1

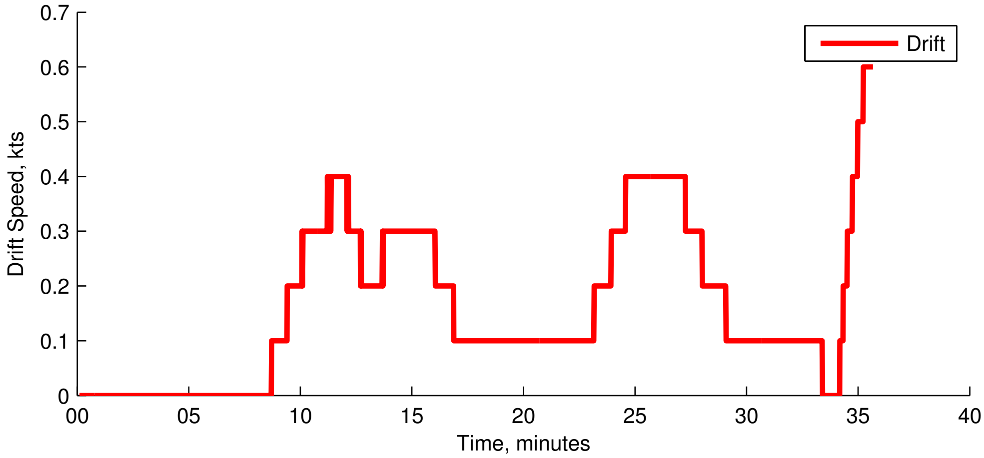


Figure 4-8: Drift Velocity Plot for Run 1

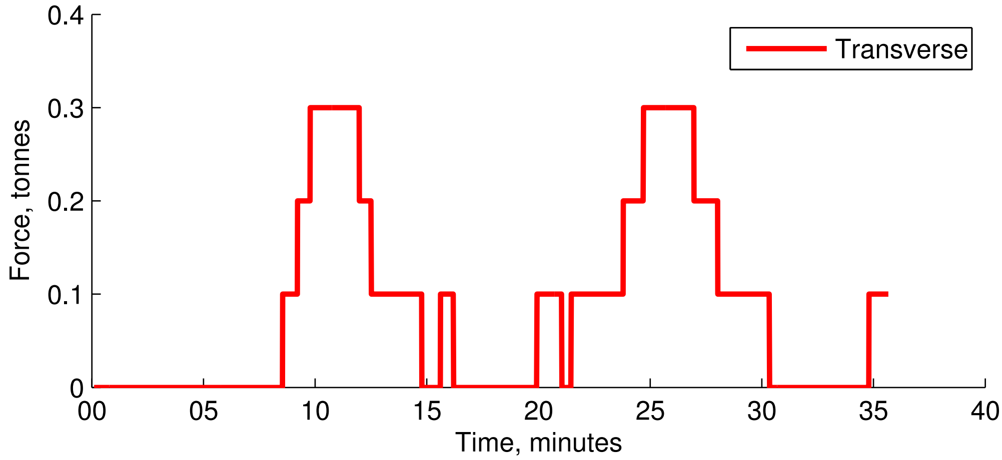


Figure 4-9: Transverse Wind Force Plot for Run 1

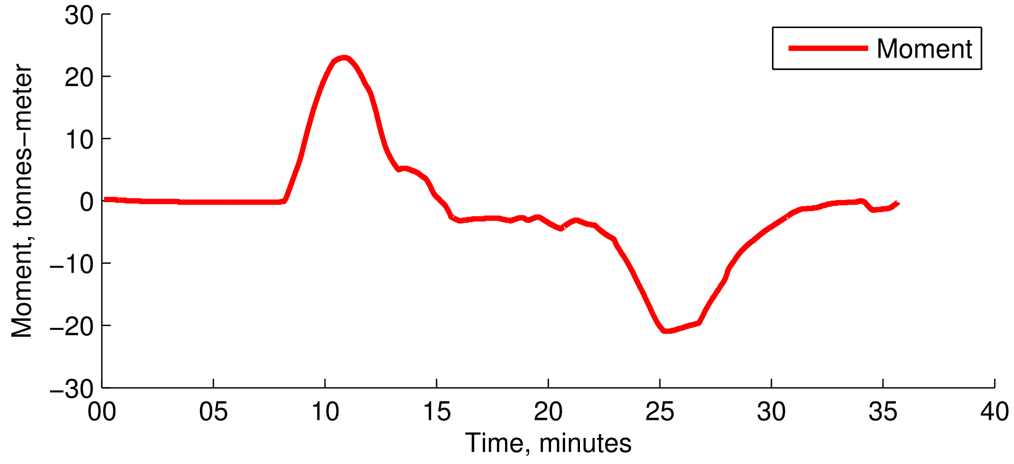


Figure 4-10: Wind Moment Force for Run 1

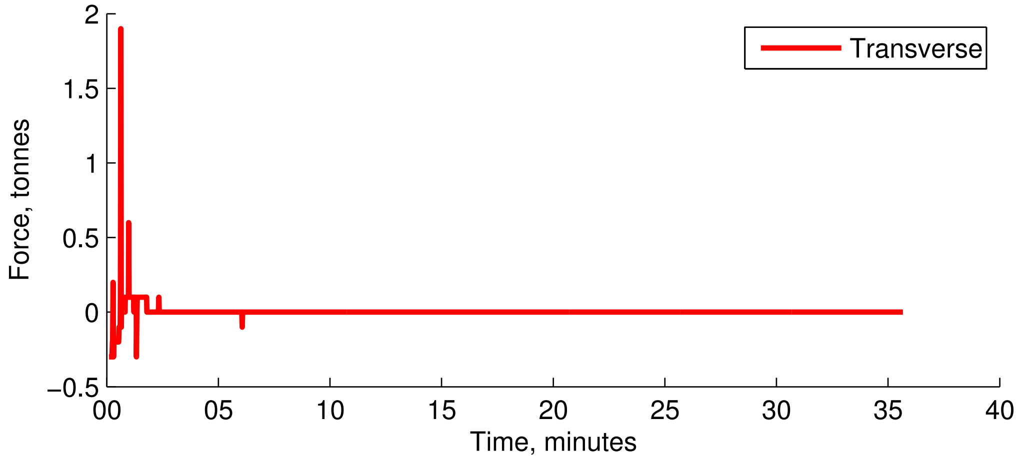


Figure 4-11: Transverse Bank Suction Force for Run 1

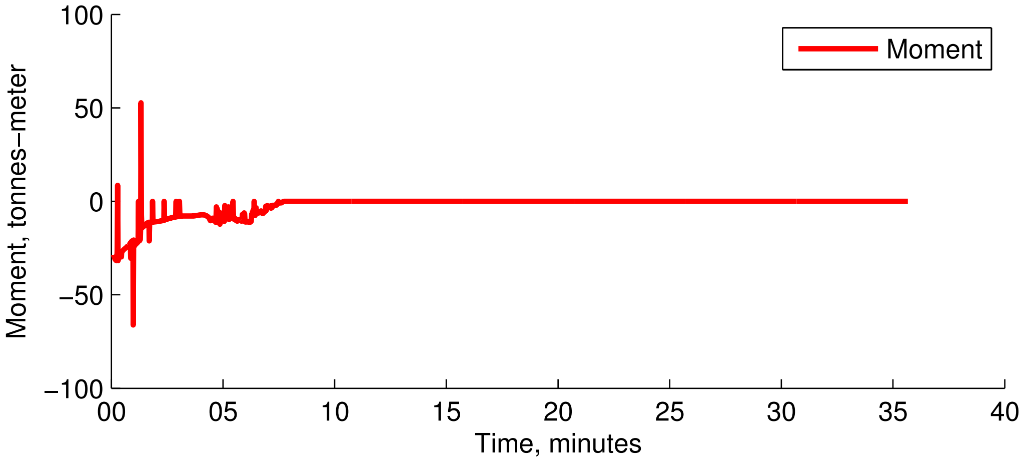


Figure 4-12: Bank Moment Force for Run 1

4.1.2 Run 2 – Inbound Winds from the West at 15 knots

Description:

The simulation begins with the ship along the proposed channel's centreline before it swings its stern to port in a manoeuvre similar to that of Run 1. Thrusters and asynchronous use of the rudders and main propulsion system are used to start and check the swing of the ship and to keep a controlled heading when backing down the channel.

Main Propulsion:

Compared to Run 1, more forward propulsion was required to maintain headway into the wind and counteract wind induced moments and transverse forces; propulsion topped out at about 60rpm forward and 60 rpm astern.

Rudder:

Starboard rudder is used up to 30 degrees both to port and to starboard with a short duration at maximum rudder displacement (35 degrees) coinciding to a powerburst from the main propulsion system used to check the stern swing to starboard while backing down the harbour channel.

Thruster:

Stern thrusters are used heavily during the manoeuvre: both during the initial swing and while backing down the harbour with some short durations of 100% power utilization. Future simulations may reduce this thruster usage by increasing the use of combine starboard propeller and rudder combination.

Wind force and moment:

Wind action on the vessel is significant and demonstrates the vulnerability of cruise ships to wind induced forces. Transverse wind force acting on the vessel while backing down the channel peaks at about 70 tonnes while the peak wind moment during the vessel's turn is about 4000 tonnes-metre.

Clearances:

Clearances are again acceptable, though the vessel encroaches on the south-eastern intersection of the approach channel and turning basin. All other clearances are acceptable.

Bank force and moment:

Bank induced forces are again minimal as the clearances to the channel are well maintained.

Depth:

UKC during the simulation is never less than 2 metres.

Overall:

Much of the propulsion is required to prevent the vessel from yielding to the wind; nevertheless, the ship is able to make the transit well within the channel limits. This wind speed illustrates the affect wind has against the large transverse areas of cruise ships, and this particular wind speed, 15 knots, seems to represent the upper limit of velocities at which this cruise ship is able to overpower the transverse wind with its equipped propulsive systems.

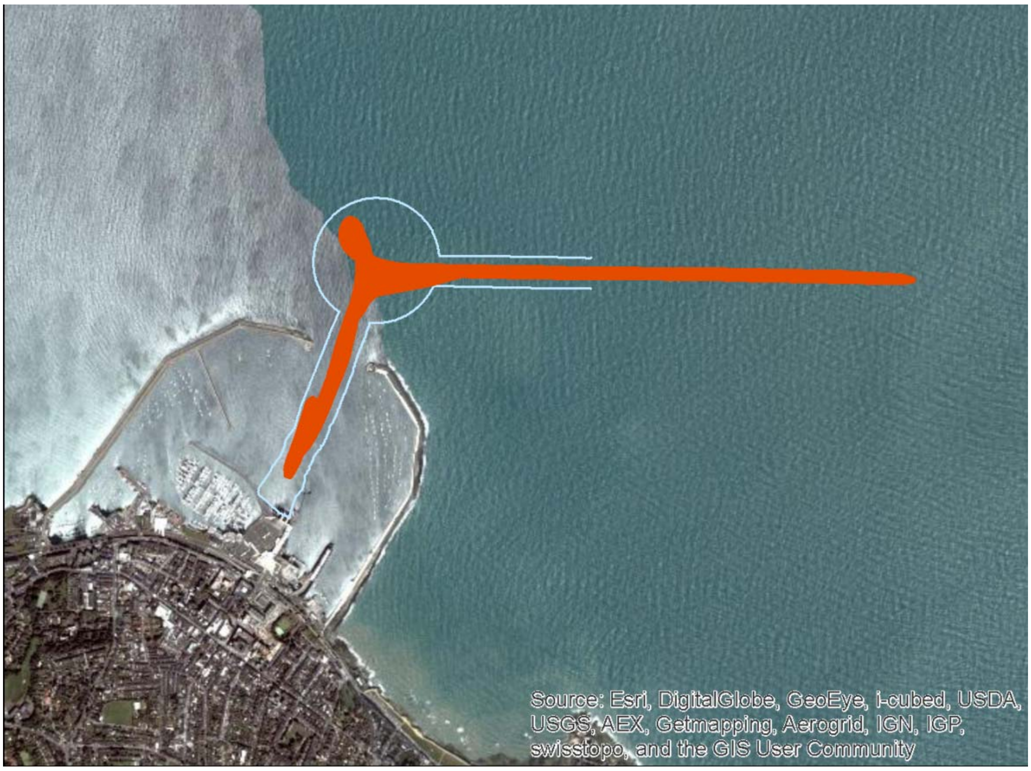


Figure 4-13: Swept Path Plot for Run 2

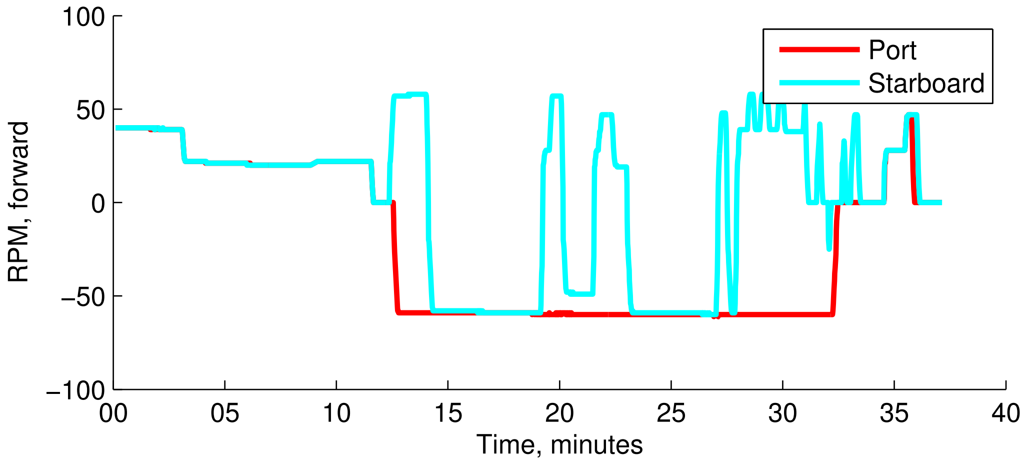


Figure 4-14: RPM Plot for Run 2

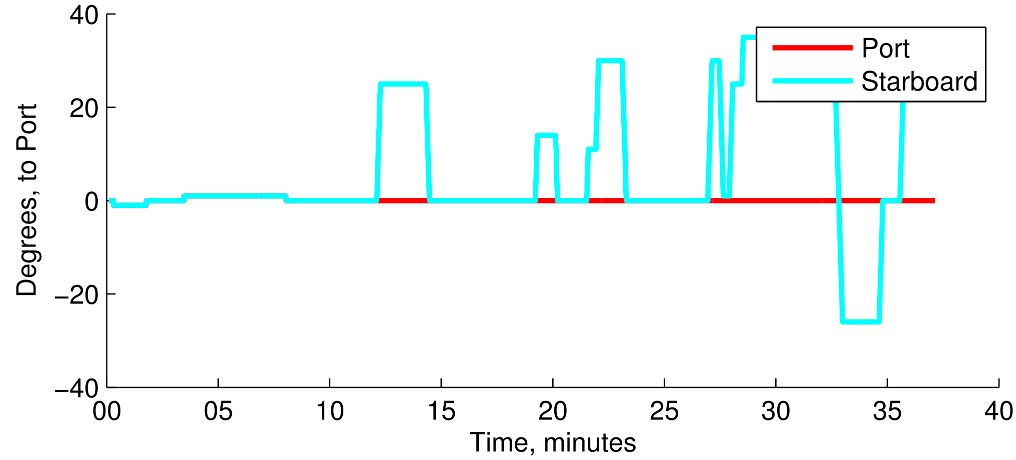


Figure 4-15: Rudder Plot for Run 2

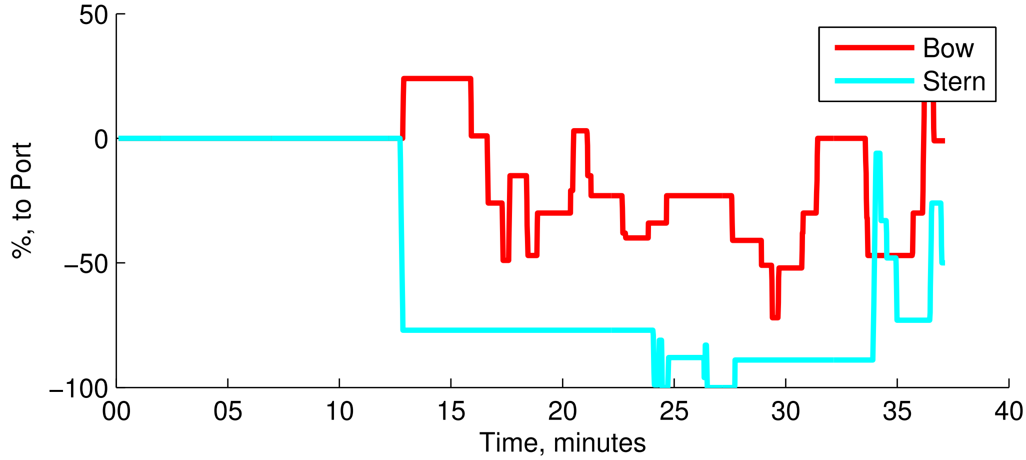


Figure 4-16: Thruster Usage Plot for Run 2

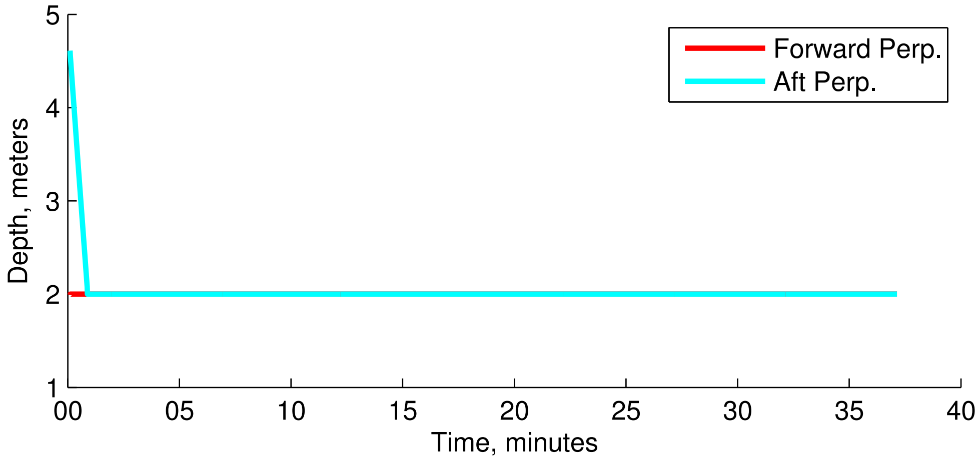


Figure 4-17: UKC Plot for Run 2

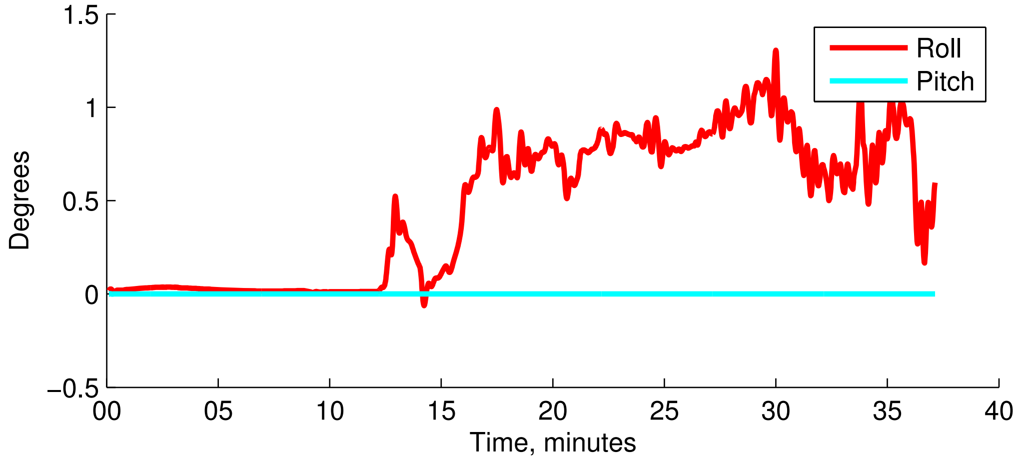


Figure 4-18: Roll and Pitch Plot for Run 2

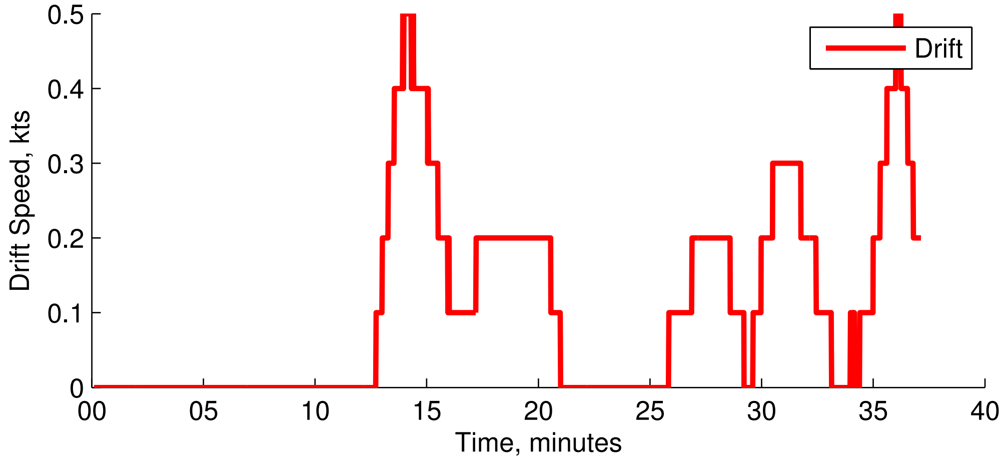


Figure 4-19: Drift Velocity Plot for Run 2

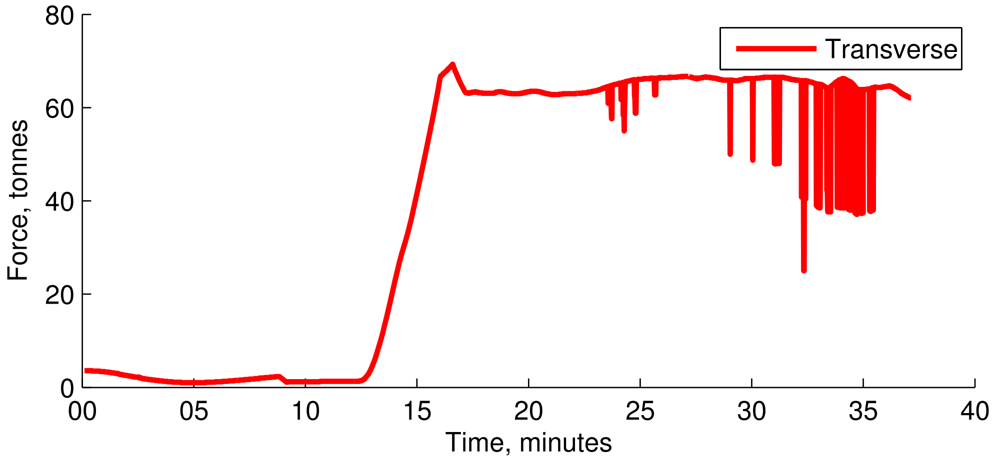


Figure 4-20: Transverse Wind Force Plot for Run 2

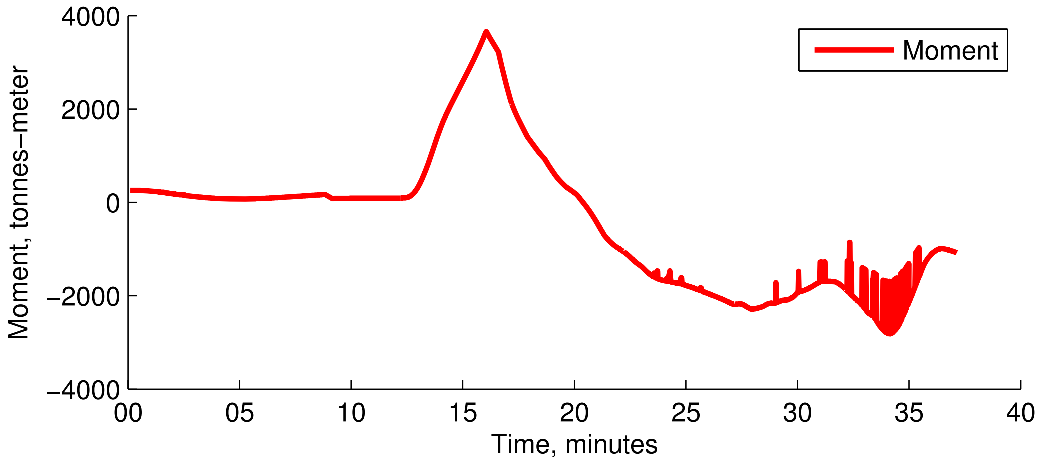


Figure 4-21: Wind Moment Force for Run 2

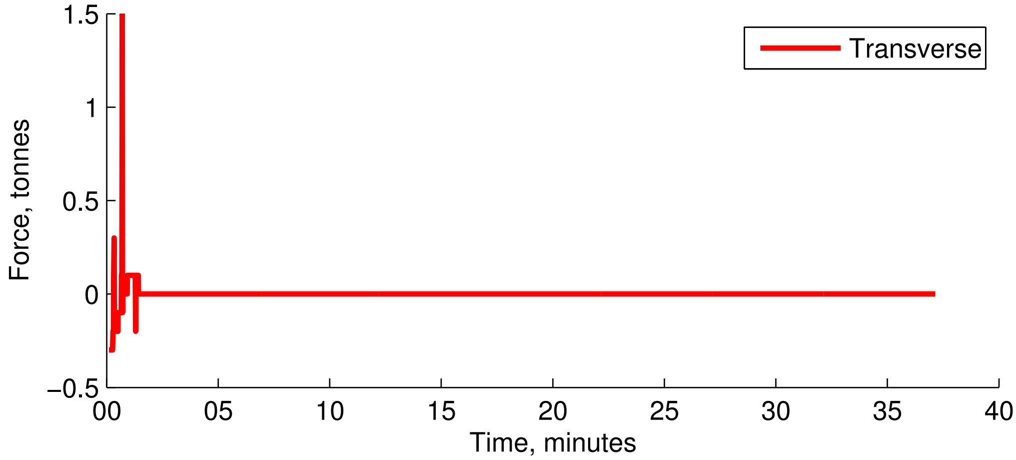


Figure 4-22: Transverse Bank Suction Force for Run 2

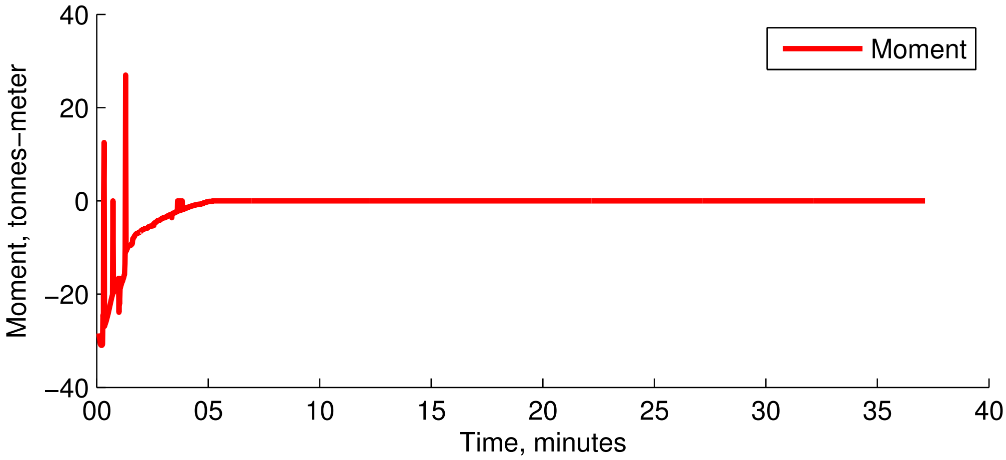


Figure 4-23: Bank Moment Force for Run 2

4.1.3 Run 3 – Inbound Winds from the Southwest at 15 knots

Description:

Initial simulations of inbound manoeuvres under south-westerly winds attempted to back the ship into the harbour in a similar fashion to Run 1. The direction and intensity of these winds prevented the vessel's stern swing to port before pushing the ship laterally out of the confines of the turning basin. This type manoeuvre was unsuccessful for many attempts and wind induced moments on the vessel were beyond the forces capable of the ships propulsive systems. Consequently, inbound manoeuvres bringing the vessel bow first into the harbour were used instead.

The ship is turned to port with some thruster propulsion and asynchronous use of main propellers and rudders. Heading in the harbour channel is then maintained with bow and thruster use.

Main Propulsion:

Main propulsion is used up to about 75 rpm forward and 100 rpm astern during the initial turn towards Dun Laoghaire harbour, to help swing the stern and check the headway of the vessel.

Rudder:

Port rudder is used for a short burst to maximum port displacement to induce transverse force for the stern swing. For the remainder of the run, rudder displacement is kept at or below 20 degrees of displacement.

Thruster:

Short bursts of the thrusters up to 75% are used during the early stages of the simulation, with smaller bursts around 50% used to maintain heading during the latter stages.

Wind force and moment:

Transverse wind force while transiting the channel is about 70 tonnes and induces about 5 degrees of drift.

Clearances:

The swing to harbour from the approach channel forces the vessel to slow in anticipation of the turn. Because of this, the wind induces a drift velocity of nearly 1 knot on the vessel and brings the stern just beyond the northern edge of the approach channel during the primary turn.

Bank force and moment:

Despite the excursion of the vessel beyond the channel limits, the stern falls into water naturally about 9.5 metres deep and experiences little bank force action.

Depth:

UKC during the stern's swing beyond the channel limits is about 1.5 metres.

Overall:

With slight channel modification at the approach channel and turning basin intersection, vessel propulsion is capable of maintaining a desirable vessel track.

Figure 4-24: Swept Path Plot for Run 3

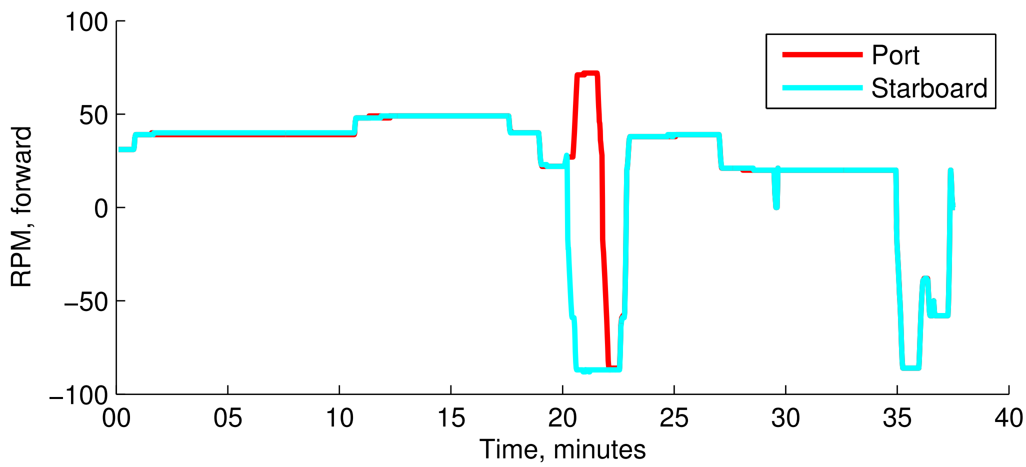


Figure 4-25: RPM Plot for Run 3

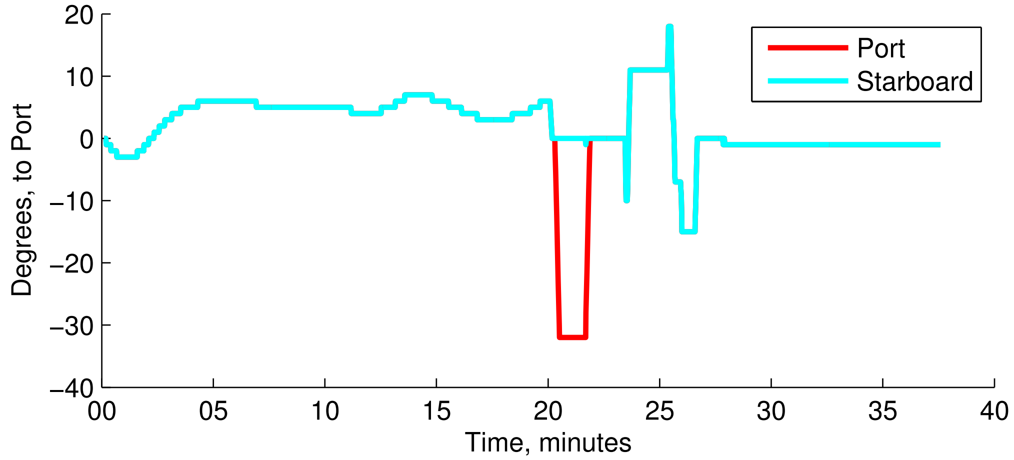


Figure 4-26: Rudder Plot for Run 3

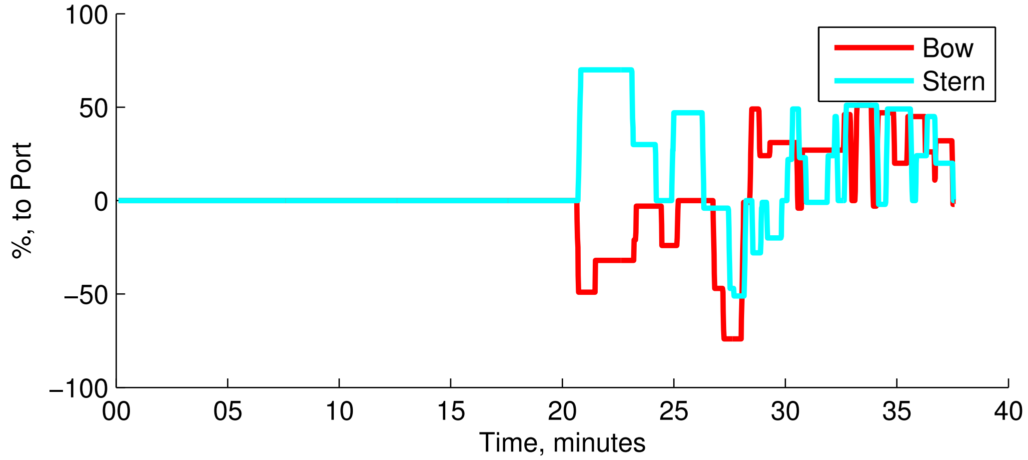


Figure 4-27: Thruster Usage Plot for Run 3

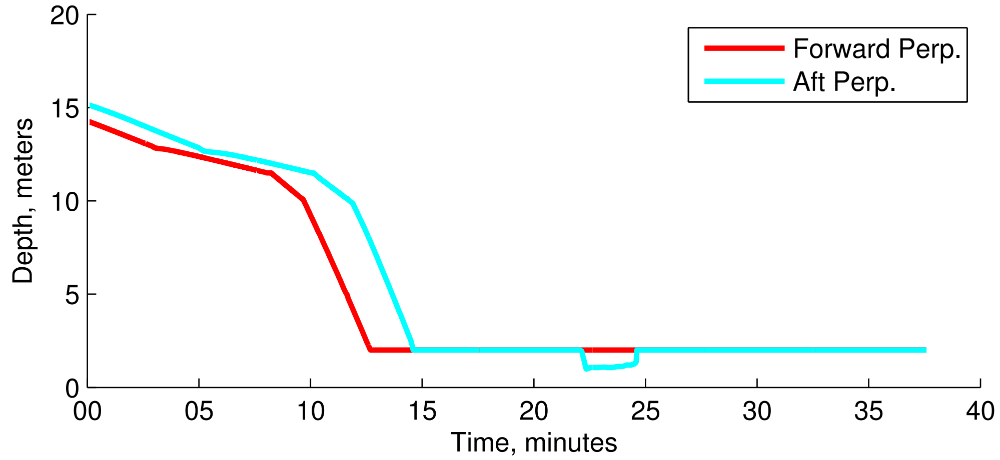


Figure 4-28: UKC Plot for Run 3

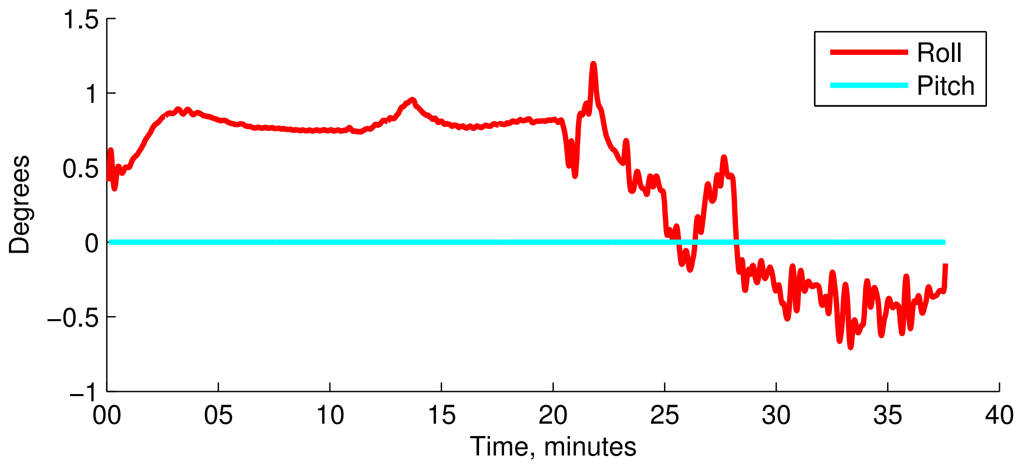


Figure 4-29: Roll and Pitch Plot for Run 3

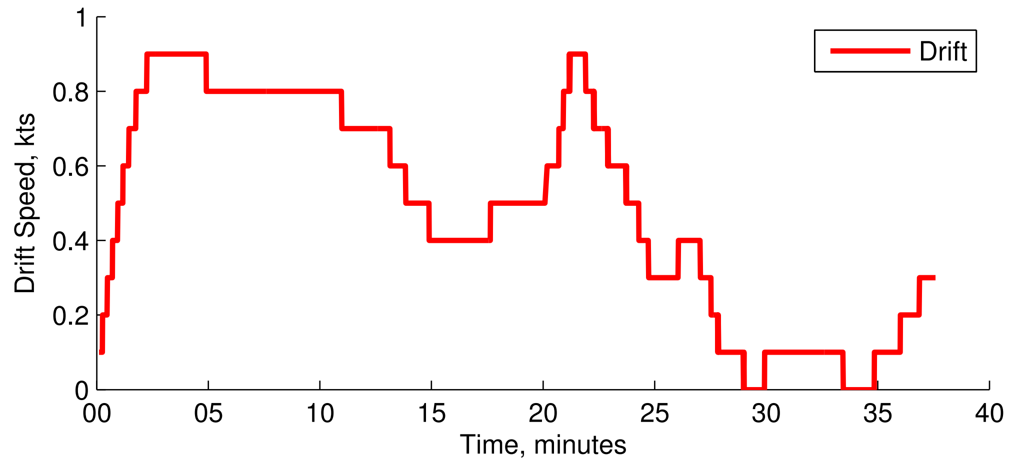


Figure 4-30: Drift Velocity Plot for Run 3

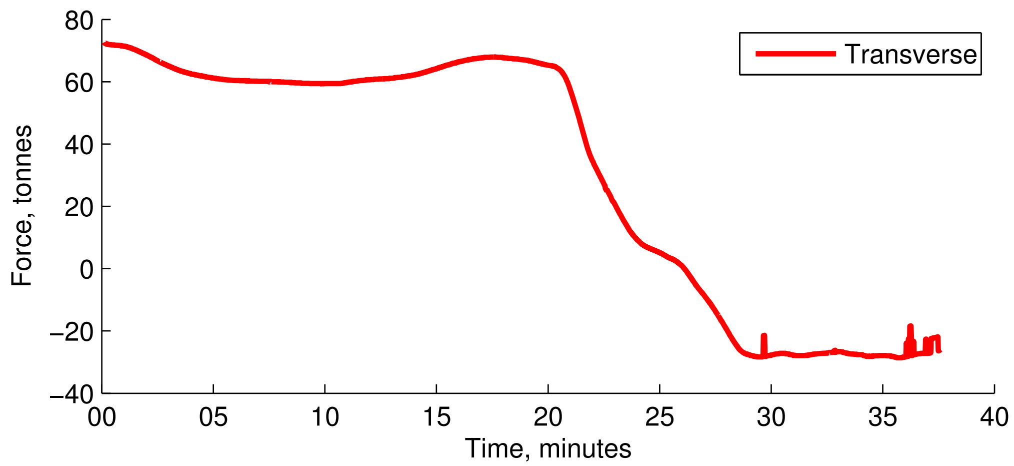


Figure 4-31: Transverse Wind Force Plot for Run 3

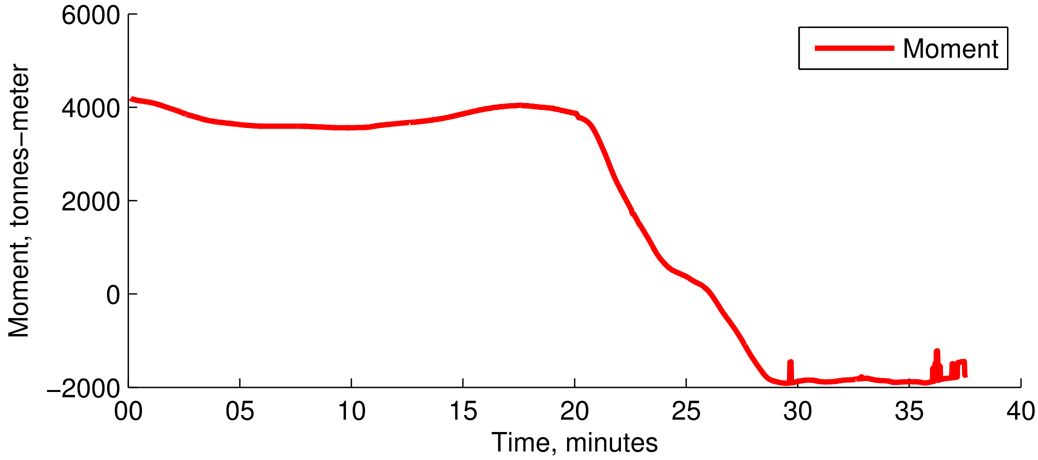


Figure 4-32: Wind Moment Force for Run 3

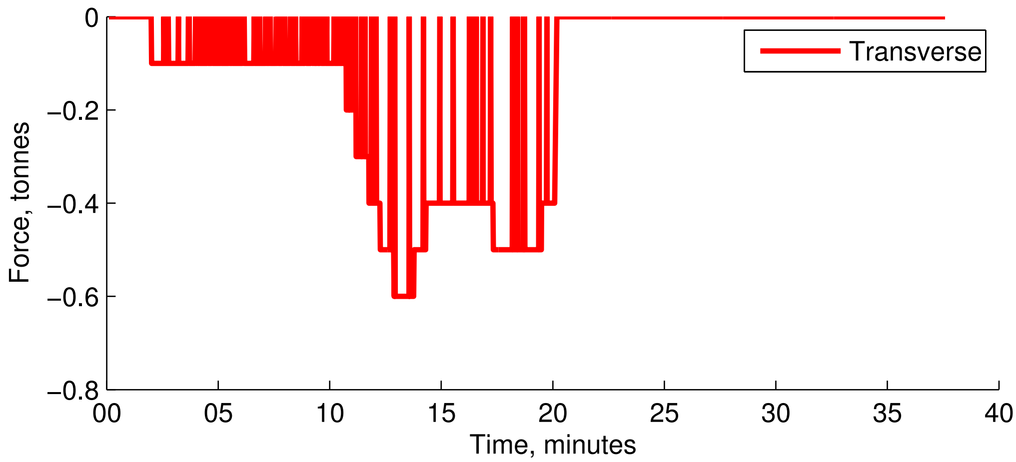


Figure 4-33: Transverse Bank Suction Force for Run 3

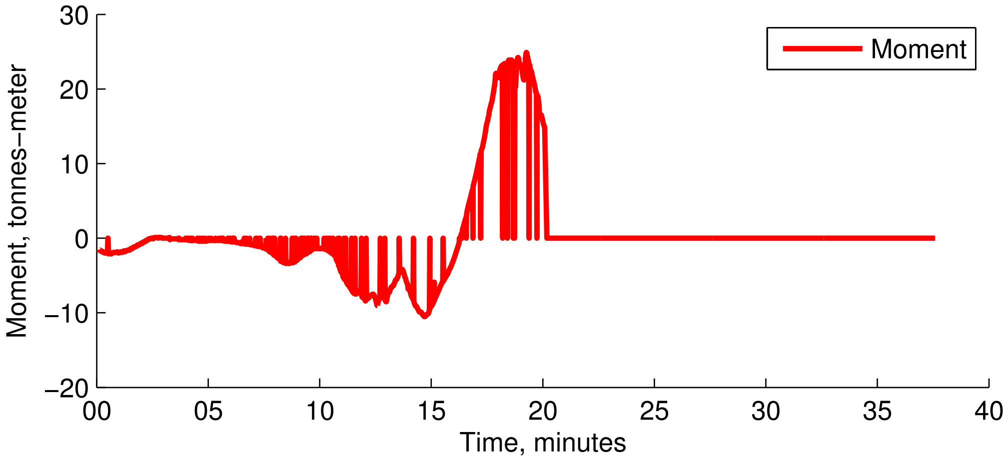


Figure 4-34: Bank Moment Force for Run 3

4.1.4 Run 4 – Inbound Winds from the South at 15 knots

Description:

This manoeuvre is similar to Run 3 in which wind speed and direction prohibited the vessel from backing into the harbour.

Main Propulsion:

Main propulsion was used conservatively, apart from a short powerburst to brake the vessel at berth.

Rudder:

Rudder was used at or below 20 degrees of displacement with the exception of a short asynchronous displacement of the port rudder to the maximum of 35 degrees during the initial swing manoeuvre.

Thruster:

Thruster usage is only used beyond 50% of total power for short bursts.

Wind force and moment:

Wind action on the vessel is less than 70 tonnes during the transit through the approach channel and peaks above 70 tonnes during the beginning stages of the turn to harbour. Wind force against the vessel while heading through the harbour channel to berth is less than 40 tonnes.

Clearances:

Similar to Run 3, the initial turn brings the starboard quarter to the northern edge of the proposed approach channel.

Bank force and moment:

Bank forces on the vessel throughout the manoeuvre are minimal and do not exceed 0.5 tonnes and 10 tonne-metres in transverse and moment force, respectively.

Depth:

UKC during the starboard quarter's excursion over the northern limits of the approach channel is above 1.75 metres.

Overall:

With slight channel modification at the approach channel and turning basin intersection, vessel propulsion is capable of maintaining a desirable vessel track.

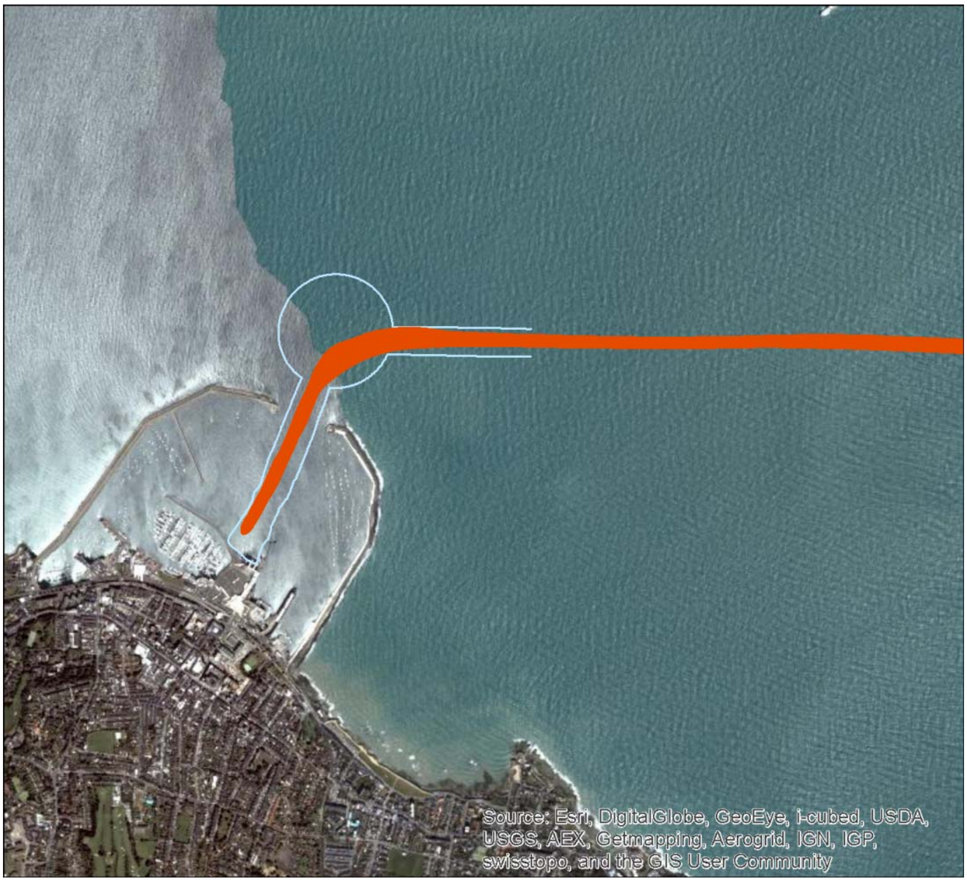


Figure 4-35: Swept Path Plot for Run 4

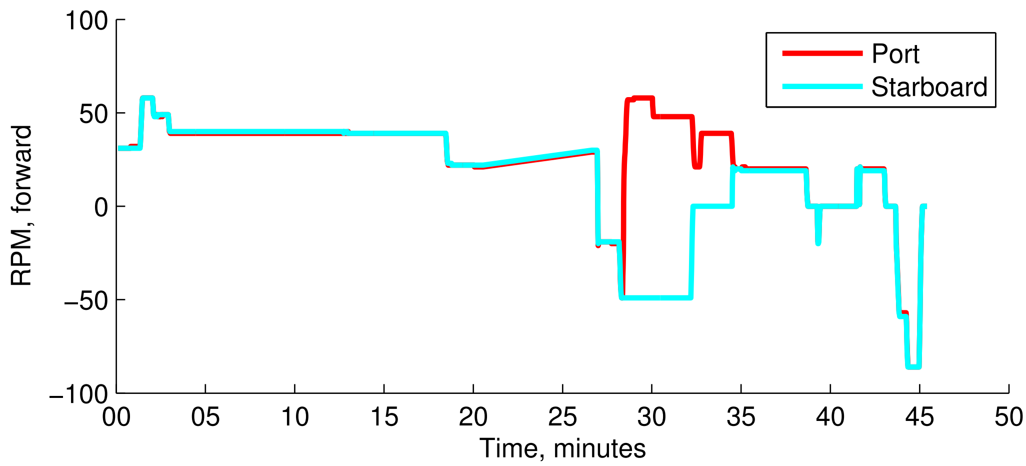


Figure 4-36: RPM Plot for Run 4

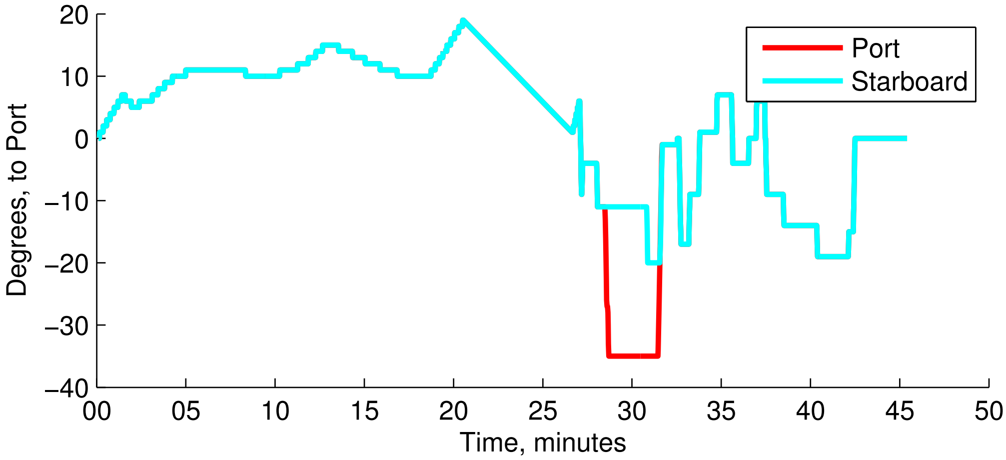


Figure 4-37: Rudder Plot for Run 4

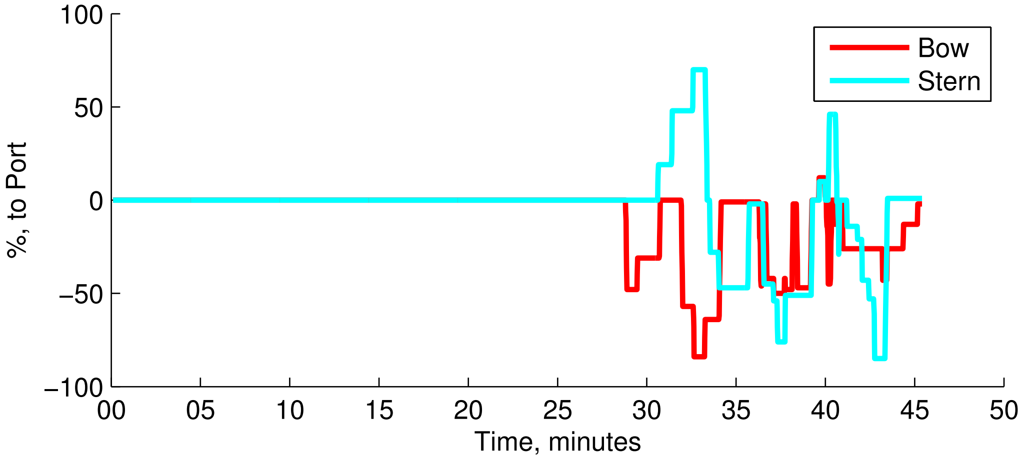


Figure 4-38: Thruster Usage Plot for Run 4

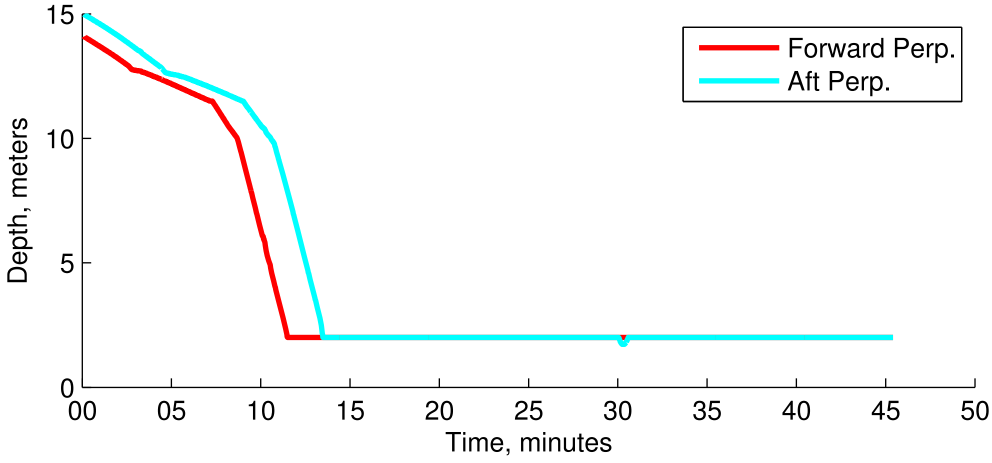


Figure 4-39: UKC Plot for Run 4

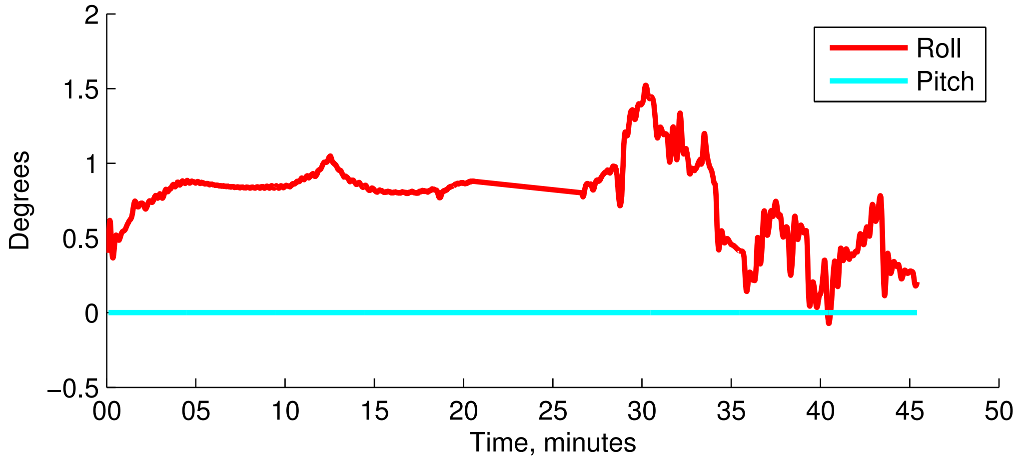


Figure 4-40: Roll and Pitch Plot for Run 4

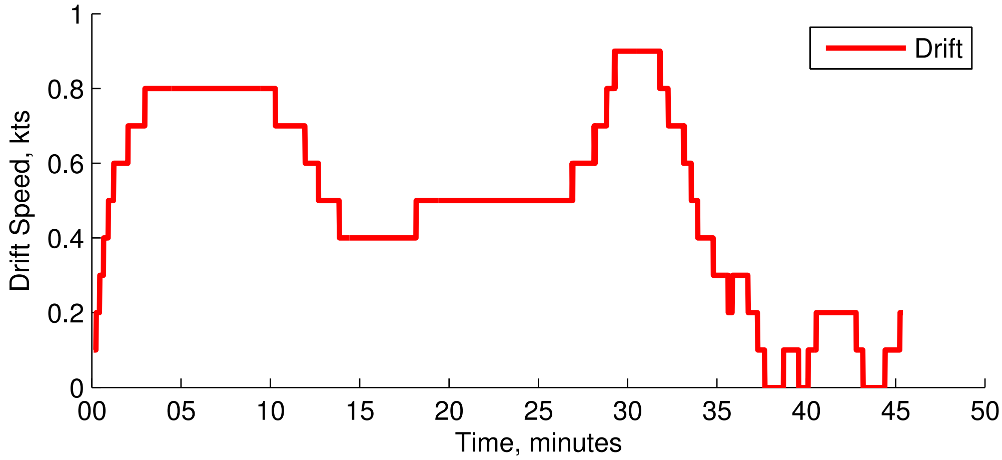


Figure 4-41: Drift Velocity Plot for Run 4

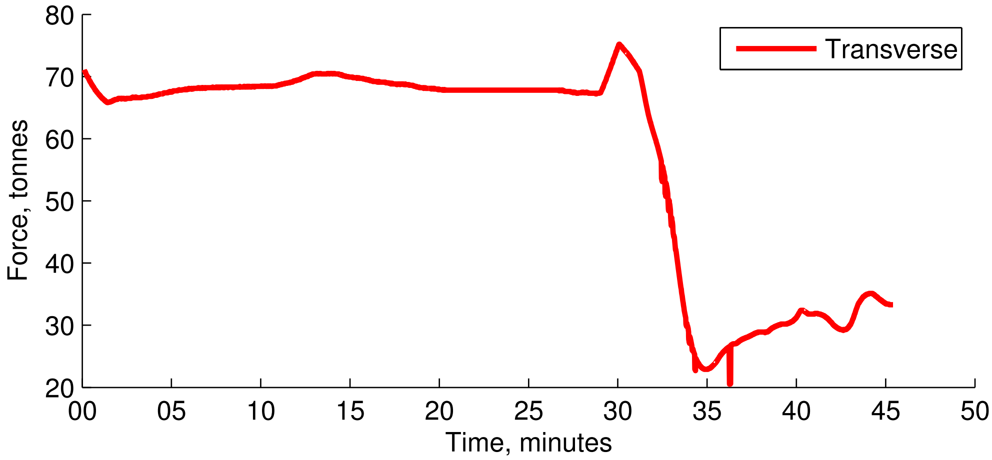


Figure 4-42: Transverse Wind Force Plot for Run 4

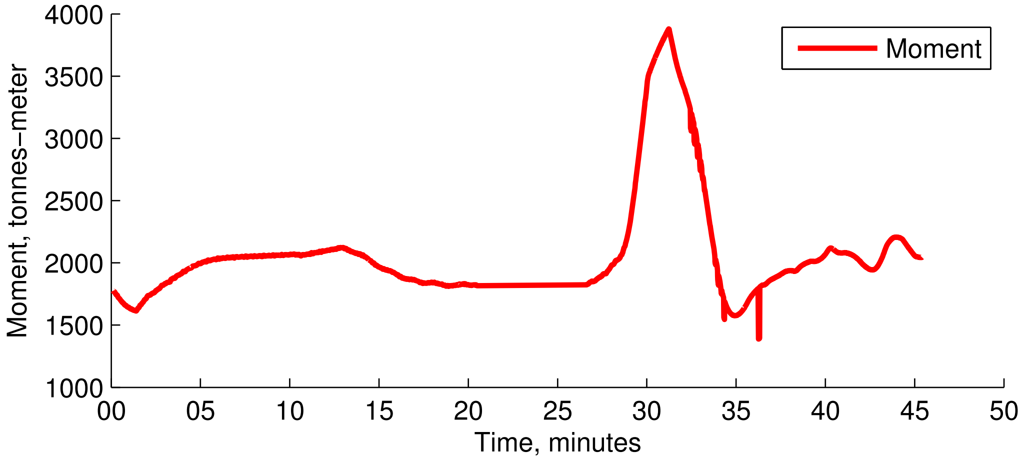


Figure 4-43: Wind Moment Force for Run 4

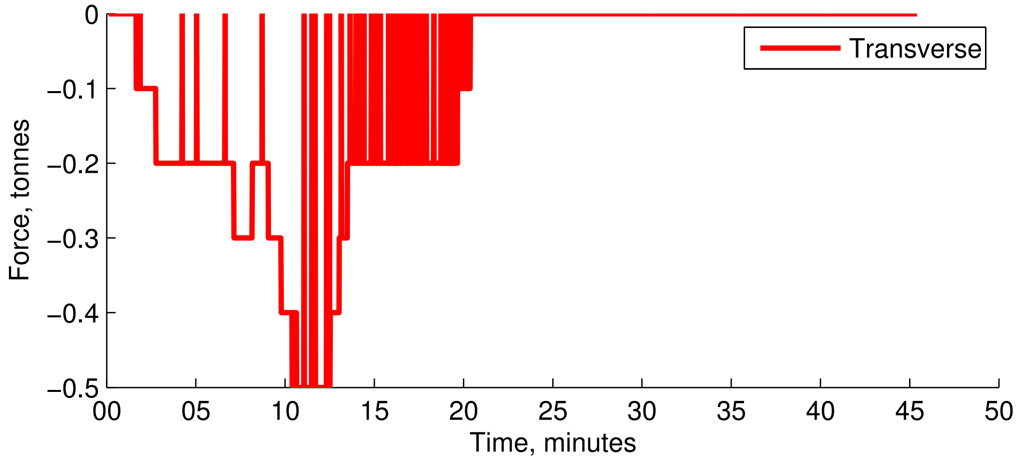


Figure 4-44: Transverse Bank Suction Force for Run 4

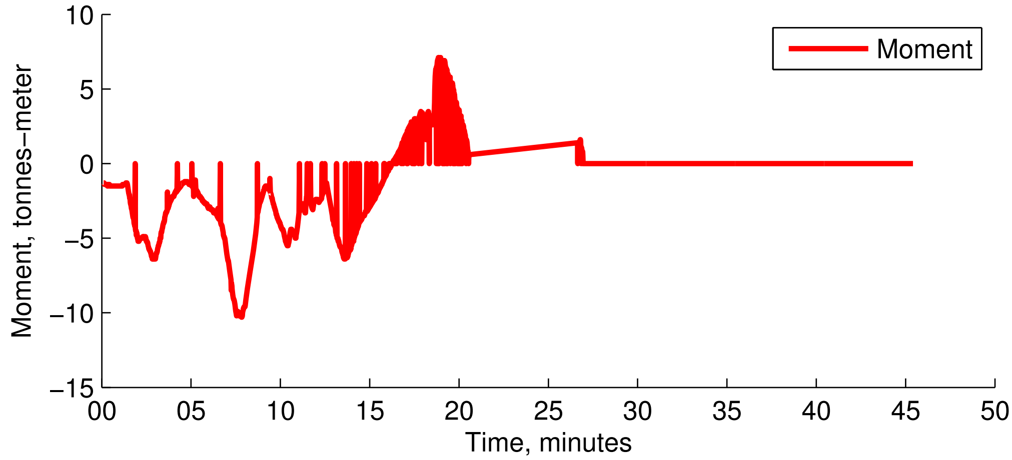


Figure 4-45: Bank Moment Force for Run 4

4.1.5 Run 5 – Outbound Bow-First Winds from the West at 15 knots

Description:

To test the outbound manoeuvres of the fixed propeller cruise ship model, two scenarios were evaluated: bow-first and stern-first departures under worst case wind scenarios. Run 5 tests the bow-first departure under 15 knot winds from the west. It was thought that the westerly winds would prevent the stern's motion to port during the turn out of the harbour and cause the vessel to ground at the northern edge of the turning basin.

Asynchronous propulsion and rudder, coupled with thruster usage is used to maintain desired heading in the harbour channel and induce the vessel's turn to starboard upon ample clearance of the ship's pivot point from the breakwaters.

Main Propulsion:

Asynchronous propulsion was used mainly to reduce headway of the vessel as a result of the wind forces acting to increase vessel speed in the channel. Rpms in excess of 75 are used for said breaking manoeuvre; apart from this action, engine settings are kept below 50 rpm with the exception of short powerbursts up to 75 rpm.

Rudder:

Rudder displacement is kept at about 25 degrees for most of the manoeuvre to maintain desired heading.

Thruster:

Stern thruster usage of 50% is maintained throughout most of the manoeuvre, while the bow thruster is used stepwise up to 50%.

Wind force and moment:

Transverse wind forces beak and hold steady around 60 tonnes for much of the outbound manoeuvre, but taper as the vessel's heading moves more westerly.

Clearances:

The vessel briefly exceeds the northern edge of the approach channel when exiting the turning basin.

Bank force and moment:

Bank forces on the vessel throughout the manoeuvre are minimal.

Depth:

The UKC at the forward perpendicular dips to 1.2 metres when the bow exceeds the northern limits of the approach channel. The stern perpendicular maintains 2 metres of UKC through the manoeuvre.

Overall:

Widening the intersection of the approach channel and proposed turning basin would improve this type of manoeuvre.

Figure 4-46: Swept Path Plot for Run 5

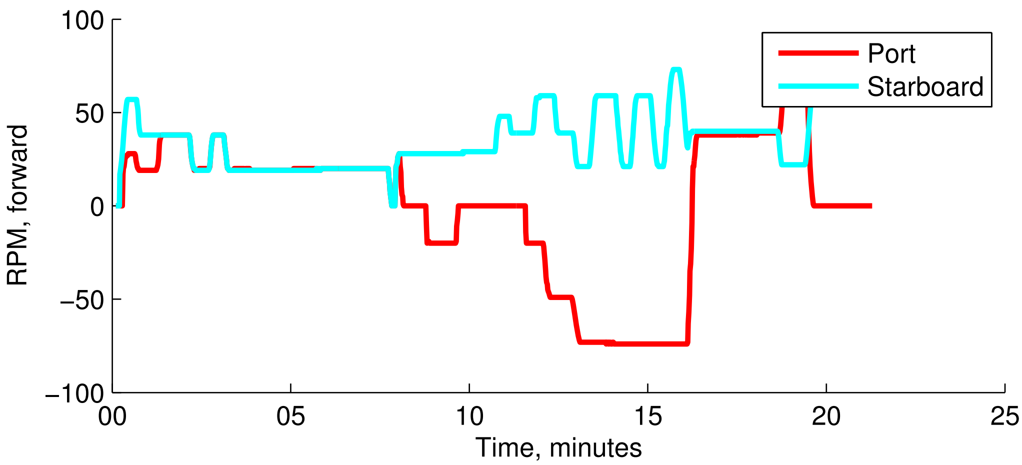


Figure 4-47: RPM Plot for Run 5

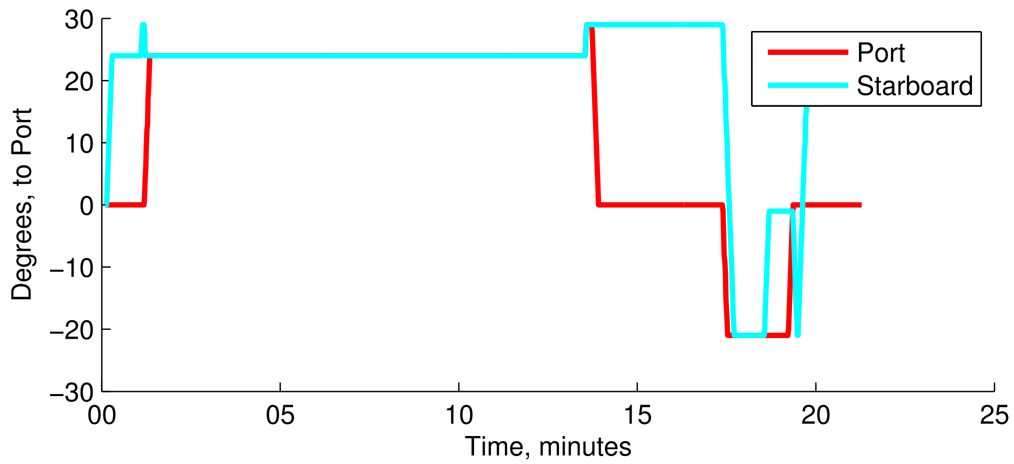


Figure 4-48: Rudder Plot for Run 5

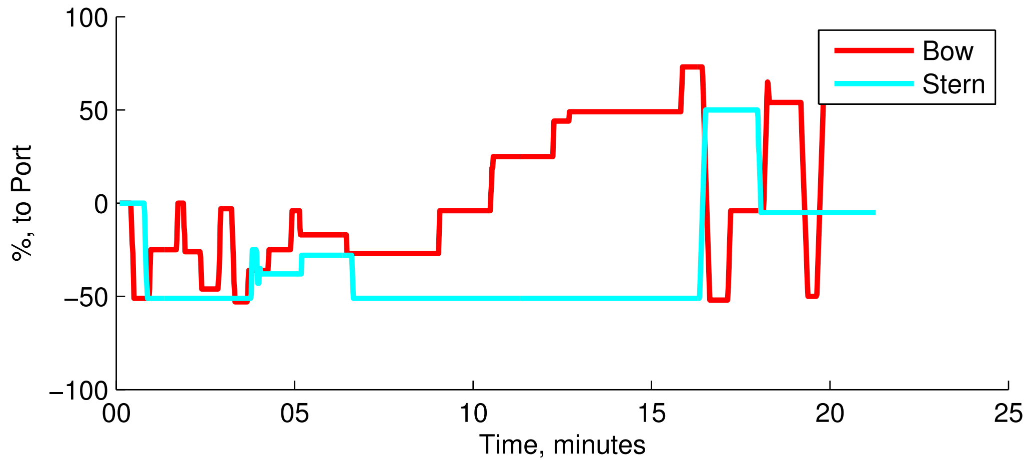


Figure 4-49: Thruster Usage Plot for Run 5

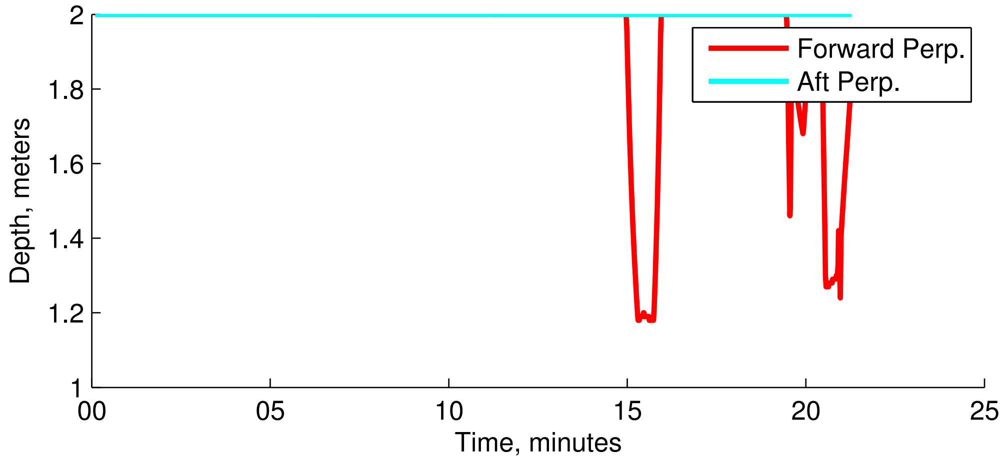


Figure 4-50: UKC Plot for Run 5

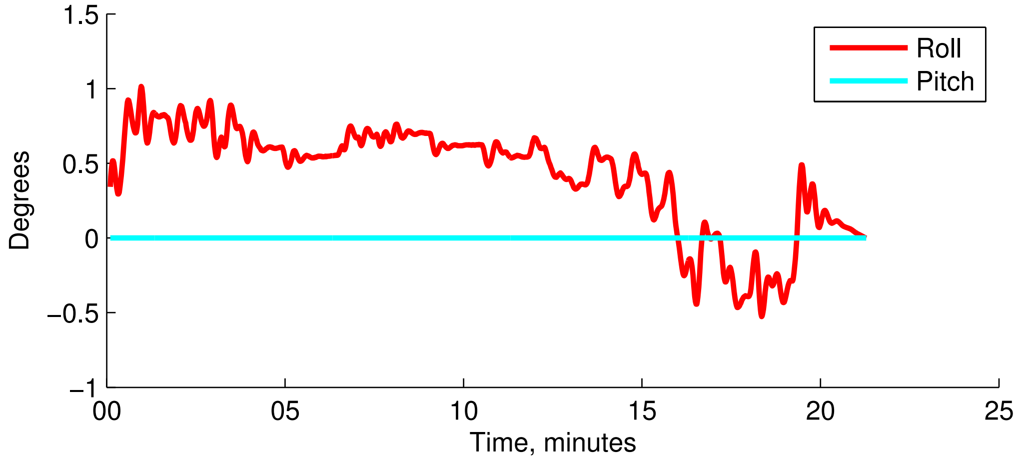


Figure 4-51: Roll and Pitch Plot for Run 5

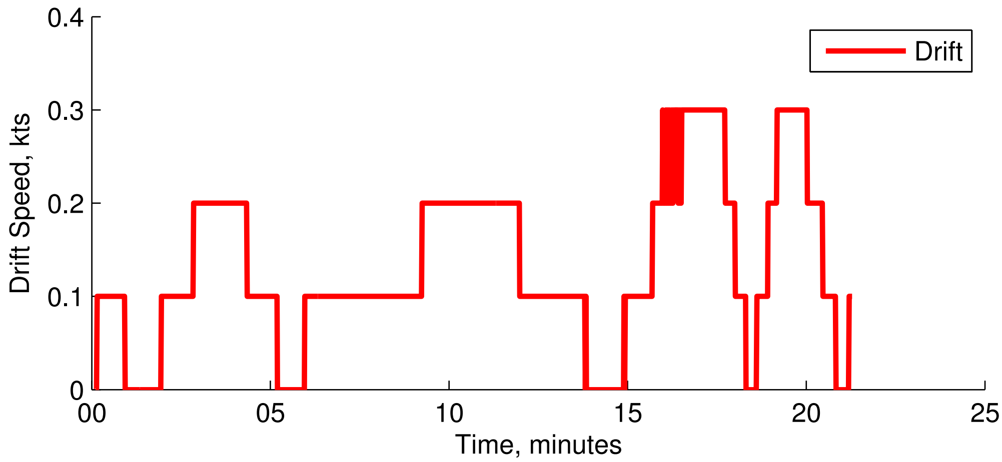


Figure 4-52: Drift Velocity Plot for Run 5

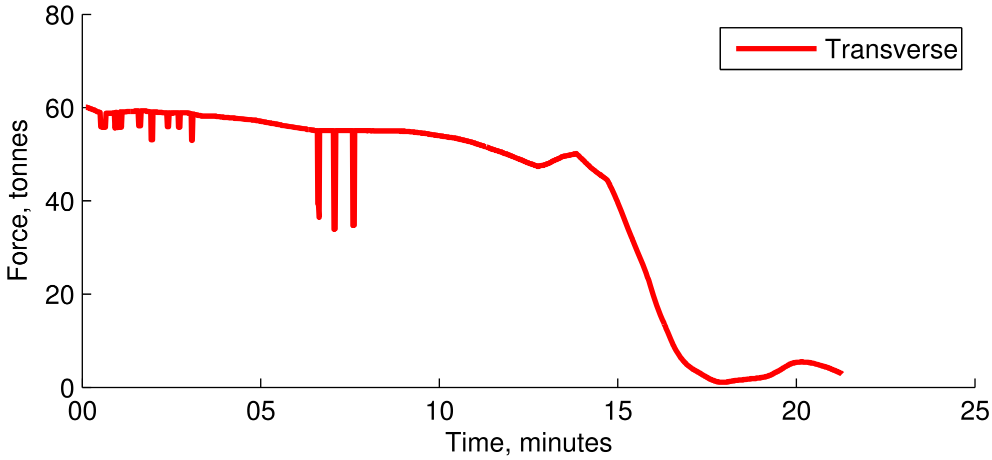


Figure 4-53: Transverse Wind Force Plot for Run 5

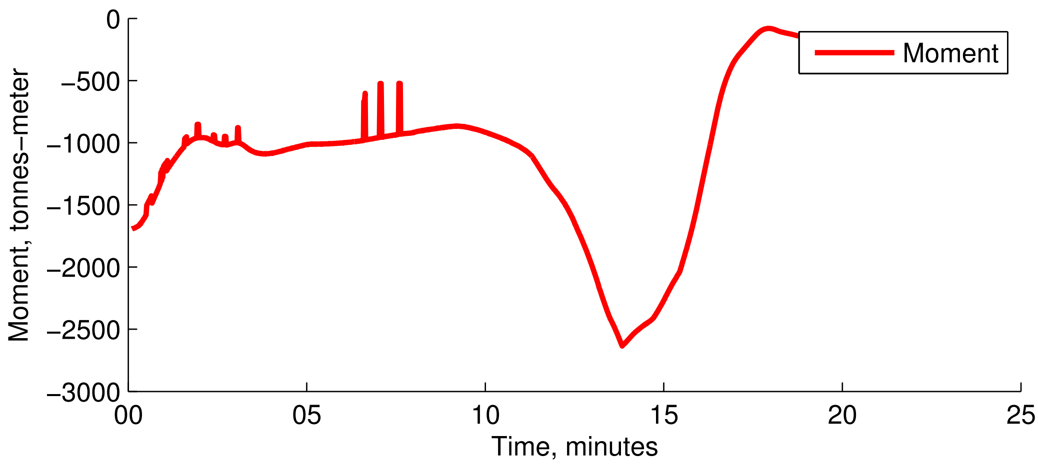


Figure 4-54: Wind Moment Force for Run 5

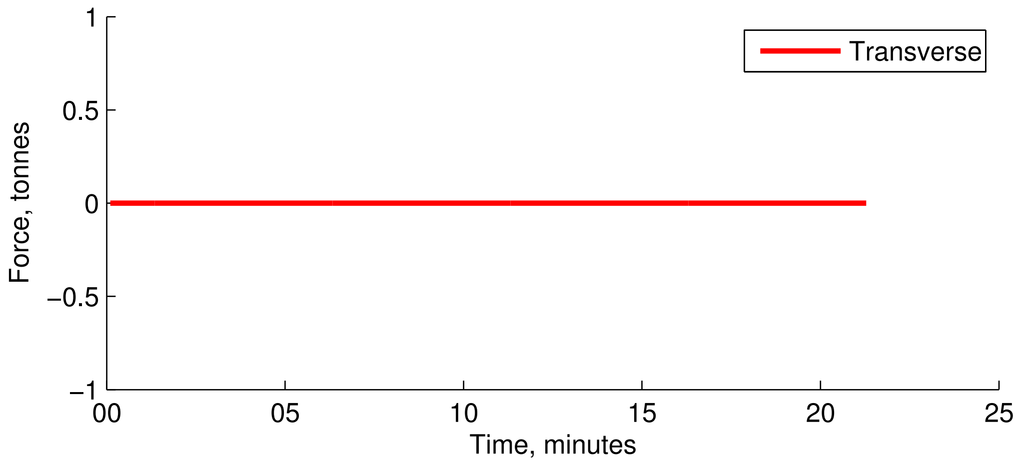


Figure 4-55: Transverse Bank Suction Force for Run 5

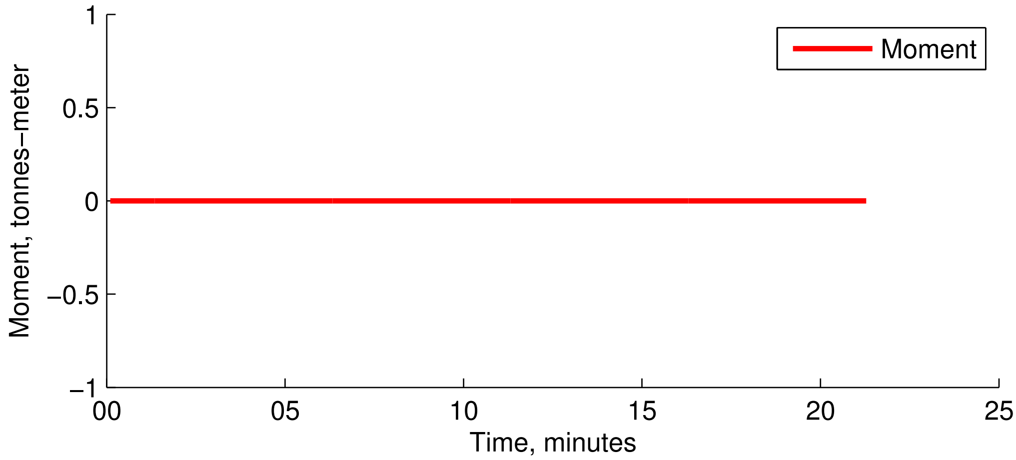


Figure 4-56: Bank Moment Force for Run 5

4.1.6 Run 6 – Outbound Stern-First Winds from the Southwest at 15 knots

Description:

Run 6 evaluates a stern-first outbound manoeuvre of the fixed propeller cruise ship. South westerly winds were simulated to test the backing manoeuvre through the channel.

Asynchronous propulsion and rudder, coupled with thruster usage is used to maintain desired heading in the harbour channel and induce the vessel's turn to port when beginning the turn to sea.

Main Propulsion:

Propulsion is kept within 40 rpm forward and astern through much of the manoeuvre, with short bursts ahead to develop headway out of the turning basin in the latter stages of the simulation.

Rudder:

Rudder displacement is minimal throughout the simulation with small bursts at 25 degrees of displacement.

Thruster:

Thruster power is kept below 50% during the backing manoeuvre and maintained at 50% during the turning portion of the simulation.

Wind force and moment:

Transverse wind forces are about 20 tonnes through the harbour channel and increase to about 60 tonnes when the ships heading approaches 90 degrees..

Clearances:

The vessel is well within the limits of the harbour channel but crabs through the intersection of the approach channel and turning basin and is just within the channel limit of that area.

Bank force and moment:

Bank forces on the vessel throughout the manoeuvre are minimal.

Depth:

The UKC throughout the simulation does not pass below 2 metres.

Overall:

This manoeuvre was well controlled and would benefit from further widening of the area making up the intersection of the turning basin and approach channel.

Figure 4-57: Swept Path Plot for Run 6

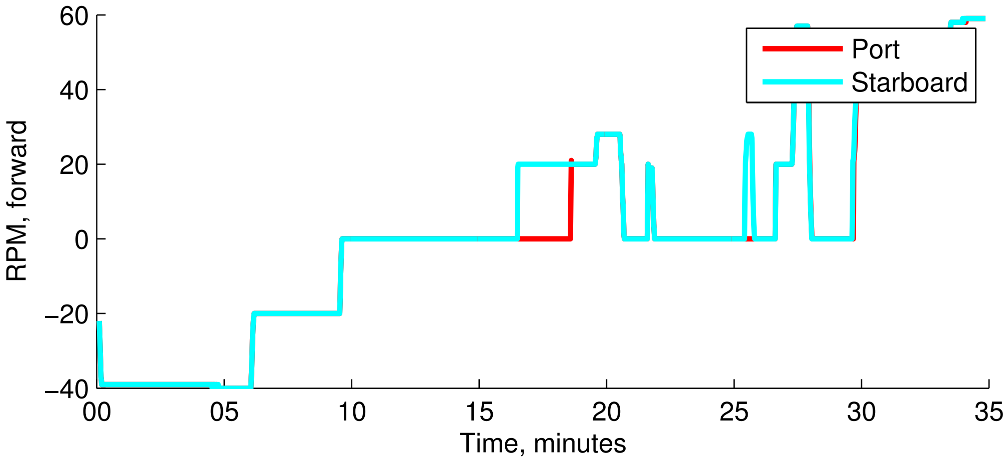


Figure 4-58: RPM Plot for Run 6

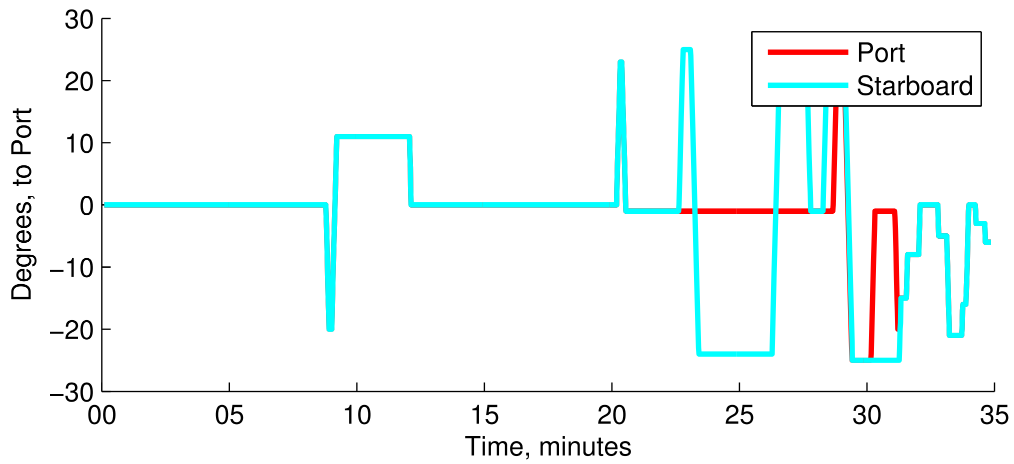


Figure 4-59: Rudder Plot for Run 6

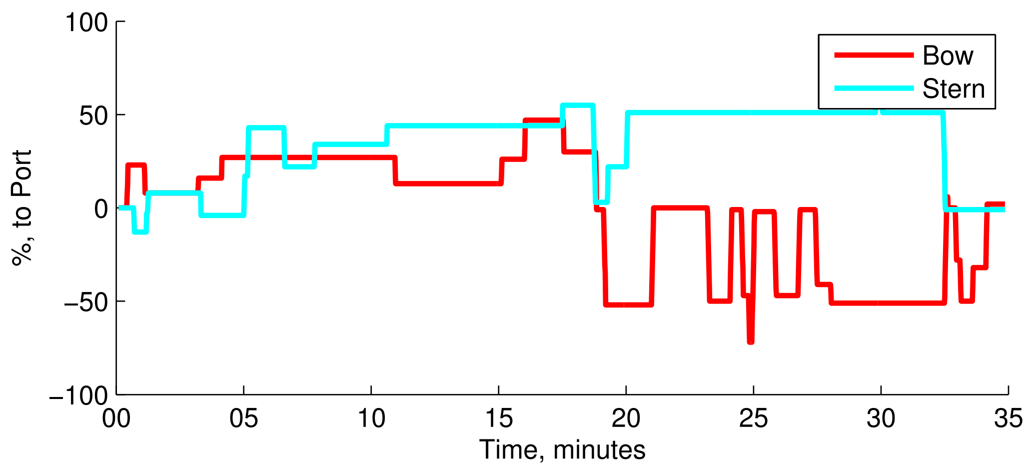


Figure 4-60: Thruster Usage Plot for Run 6

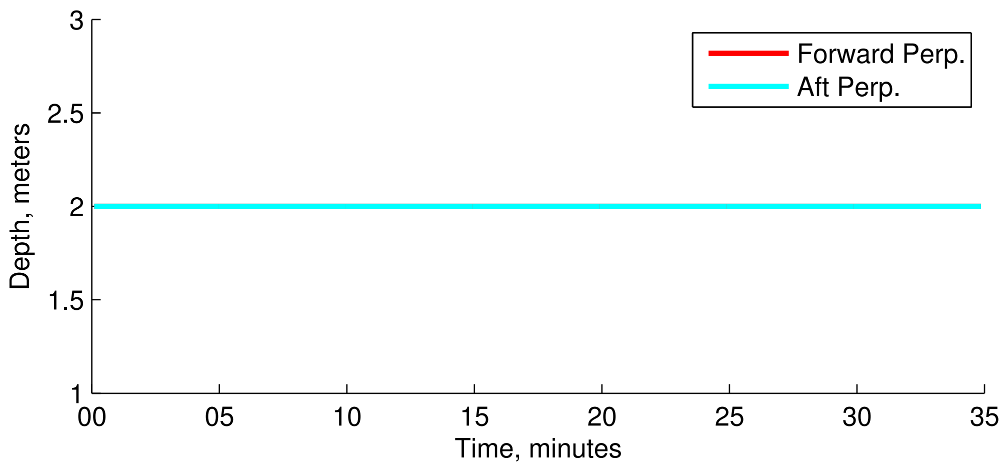


Figure 4-61: UKC Plot for Run 6

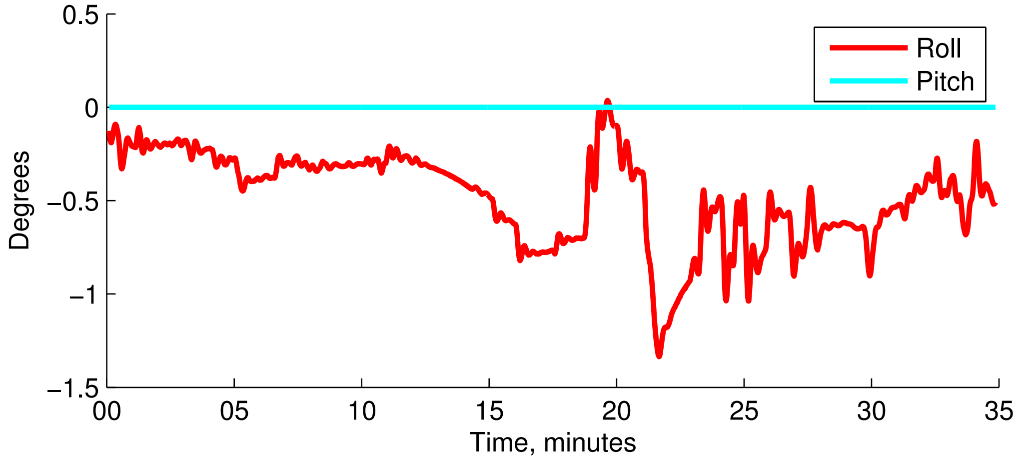


Figure 4-62: Roll and Pitch Plot for Run 6

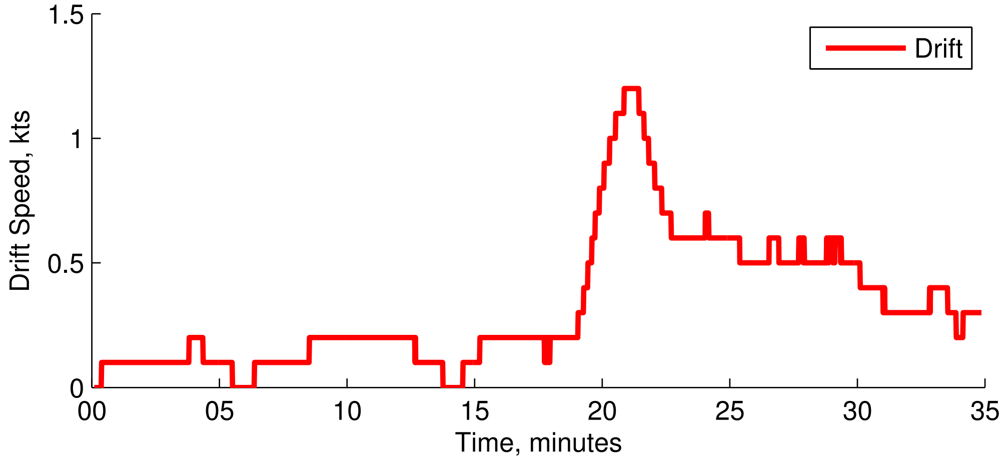


Figure 4-63: Drift Velocity Plot for Run 6

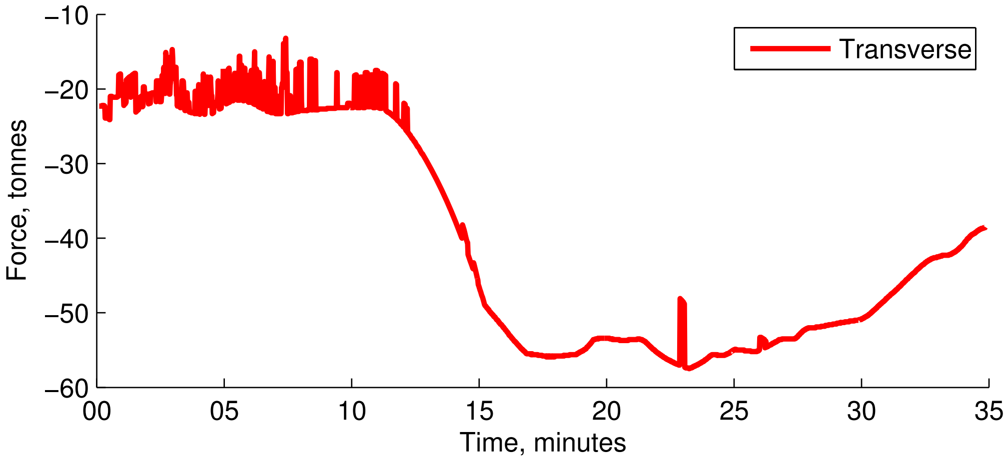


Figure 4-64: Transverse Wind Force Plot for Run 6

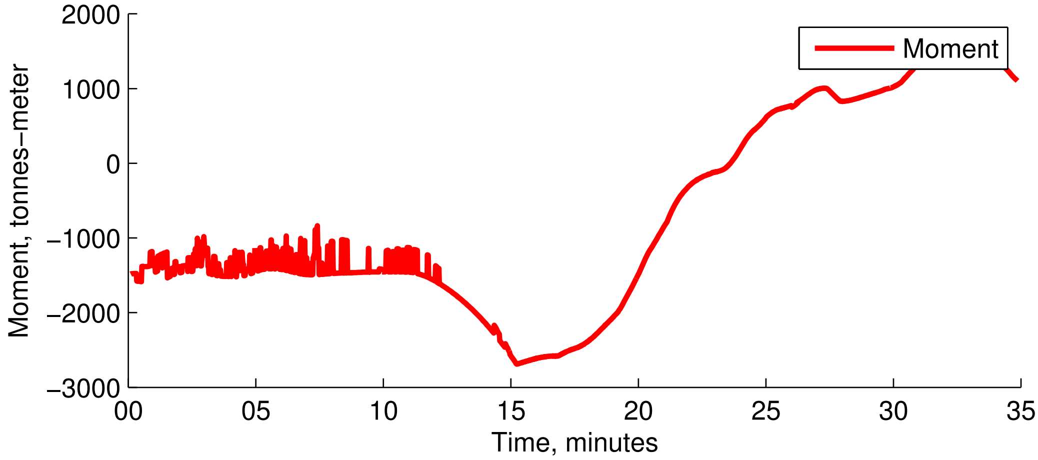


Figure 4-65: Wind Moment Force for Run 6

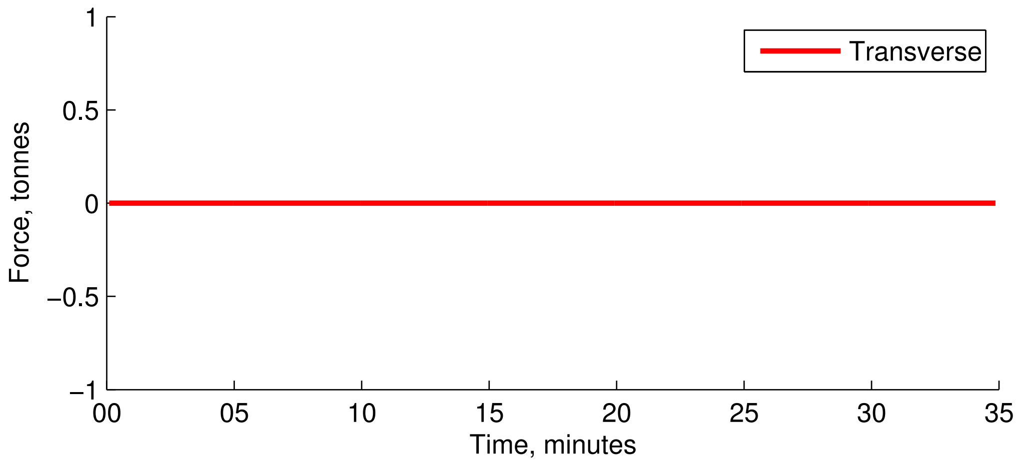


Figure 4-66: Transverse Bank Suction Force for Run 6

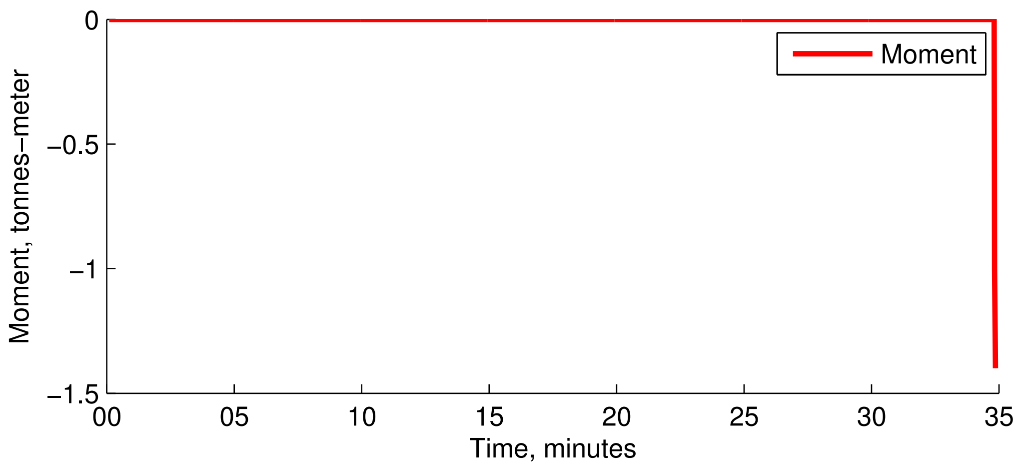


Figure 4-67: Bank Moment Force for Run 6

4.2 AZIPOD PROPULSION CRUISE SHIP

It should be noted in the following sections that figures indicating rudder angle correspond to the angle of the two Azipod units on the ship model.

Figure 4-68: Visual Channel Output of the Azipod Cruise Ship Leaving Dun Laoghaire Harbour

4.2.1 Run 7 – Inbound Mild Conditions

Description:

The modelled manoeuvre bringing the Azipod equipped cruise ship into the harbour has the vessel enter the turning basin and pivot at a point just forward of amidships using its starboard pod and bow thrusters. Sternway through the harbour channel is achieved with the port pod and heading is maintained with the bow thrusters and starboard pod.

Main Propulsion:

Main propulsion is fairly mild throughout the manoeuvre with periodic bursts on the starboard pod for turning in the basin and steerage through the harbour channel requirements.

Rudder:

The port pod is aligned with the vessels centreline axis to provide longitudinal thrust while the starboard pod is aligned 90 degrees to this for transverse force generation.

Thruster:

The bow thruster is used at or below 50% for most of the manoeuvre with small bursts to invoke more bow swing during the initial pivot towards harbour channel alignment in the turning basin.

Wind force and moment:

Wind action on the vessel is negligible (< 8 tonne transversely) due to the low 5 knot ambient winds.

Clearances:

The vessel is well controlled throughout the manoeuvre and maintains ample clearances to the proposed channel limits.

Bank force and moment:

Bank forces are virtually non-existent throughout the manoeuvre.

Depth:

UKC bottoms out around 2.35 metres but is about 2.5 metres for most of the manoeuvre.

Overall:

This preliminary manoeuvre yields forces well within the controllable limits of the vessel and provides channel clearances that are deemed acceptable.

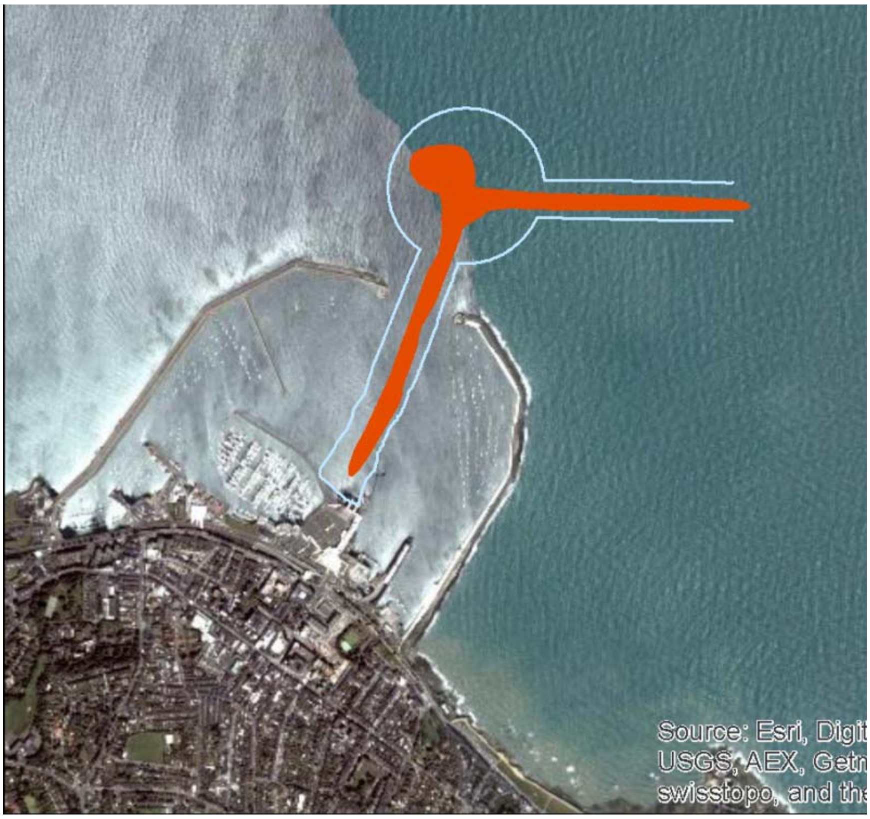


Figure 4-69: Swept Path Plot for Run 7

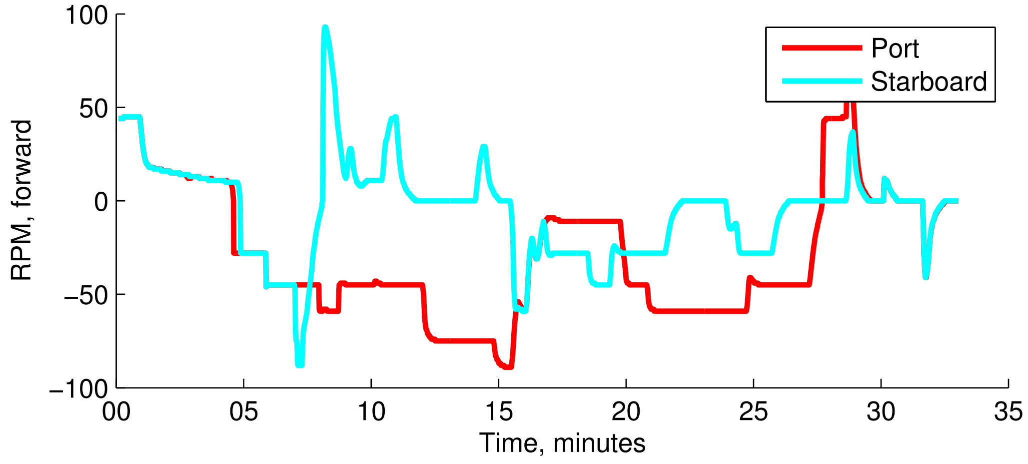


Figure 4-70: RPM Plot for Run 7

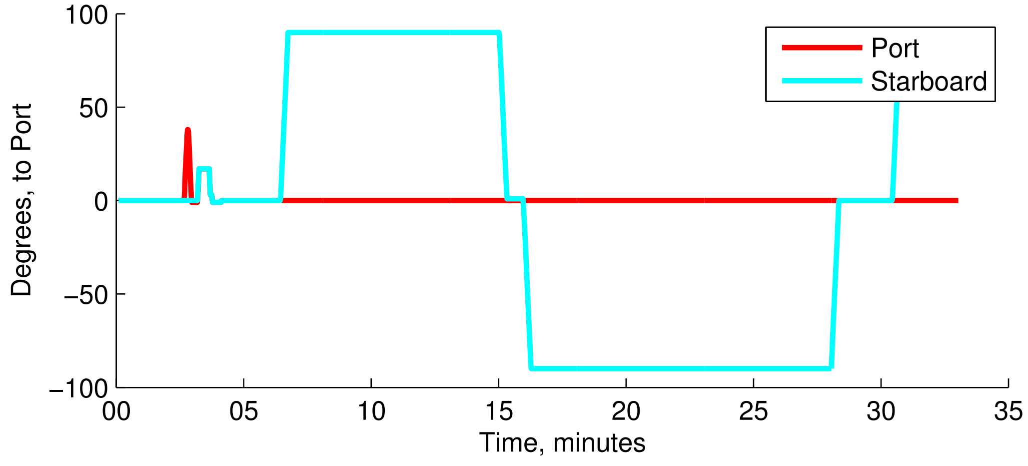


Figure 4-71: Rudder Plot for Run 7

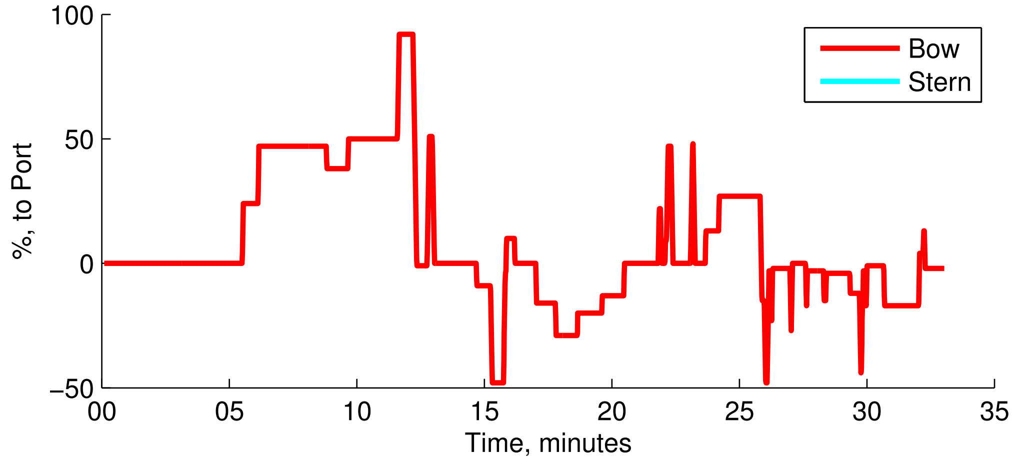


Figure 4-72: Thruster Usage Plot for Run 7

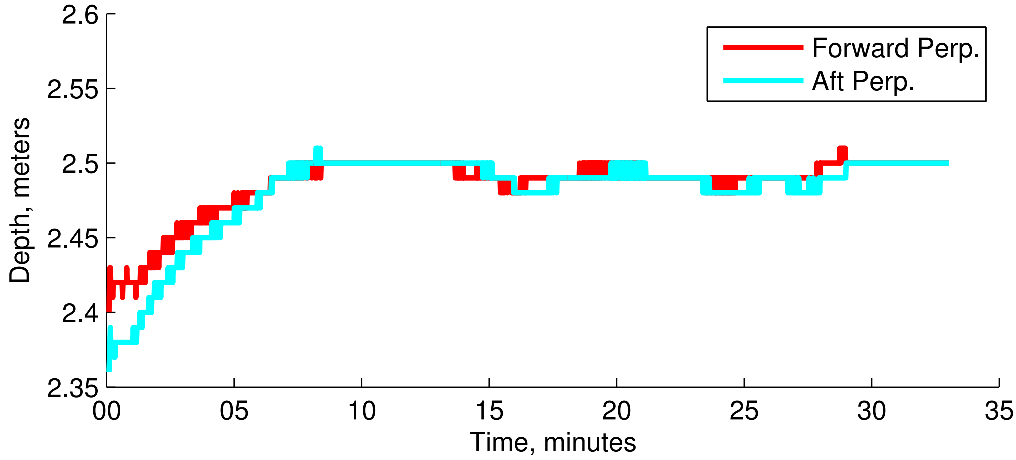


Figure 4-73: UKC Plot for Run 7

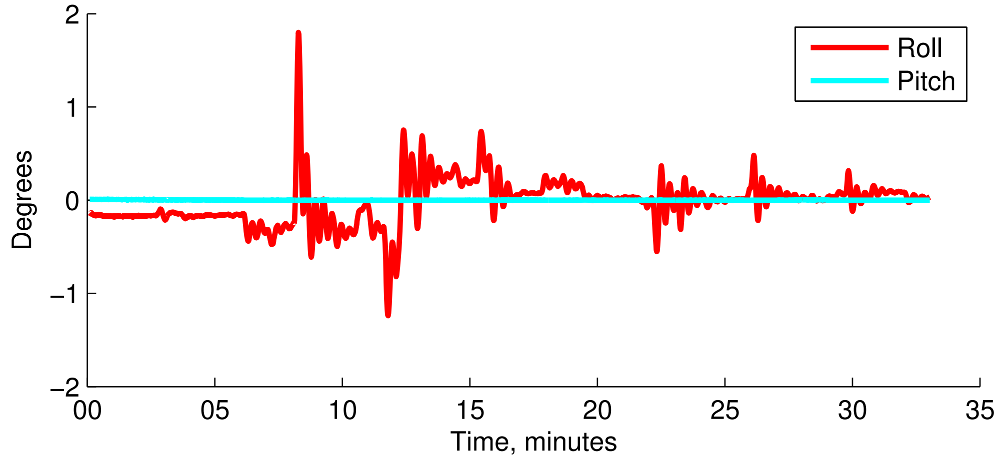


Figure 4-74: Roll and Pitch Plot for Run 7

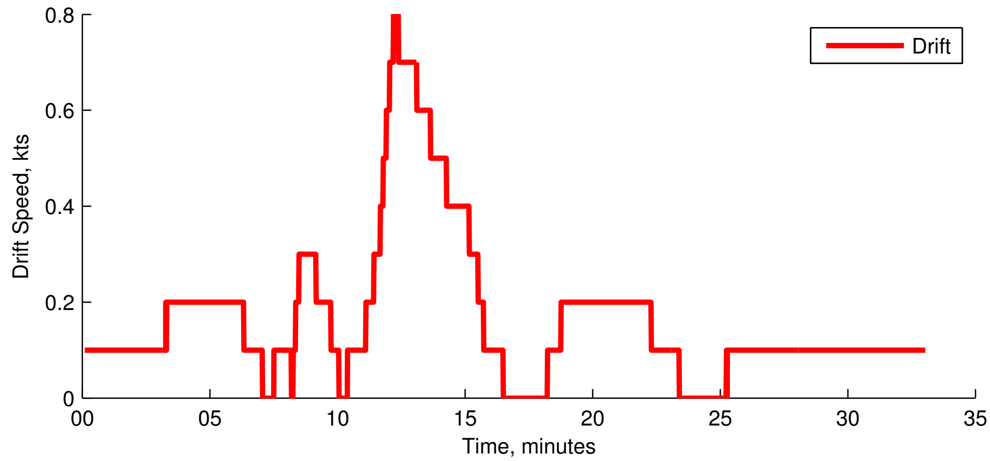


Figure 4-75: Drift Velocity Plot for Run 7

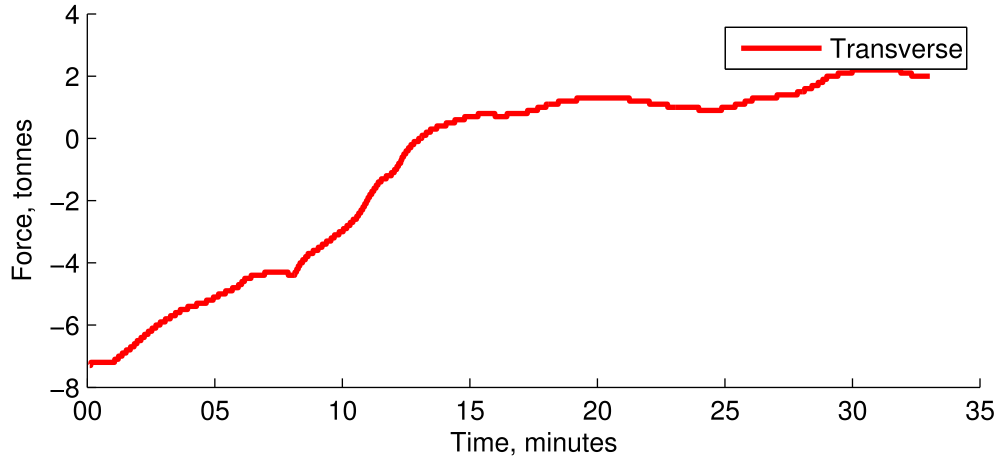


Figure 4-76: Transverse Wind Force Plot for Run 7

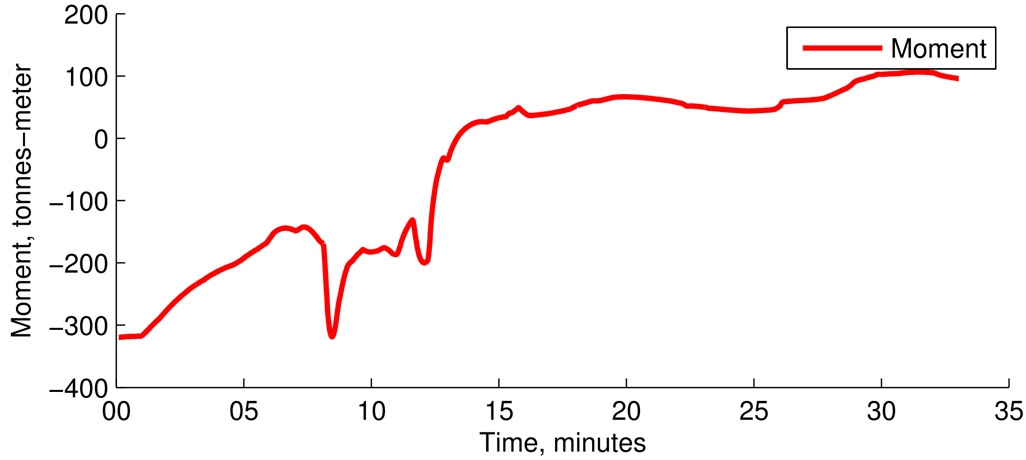


Figure 4-77: Wind Moment Force for Run 7

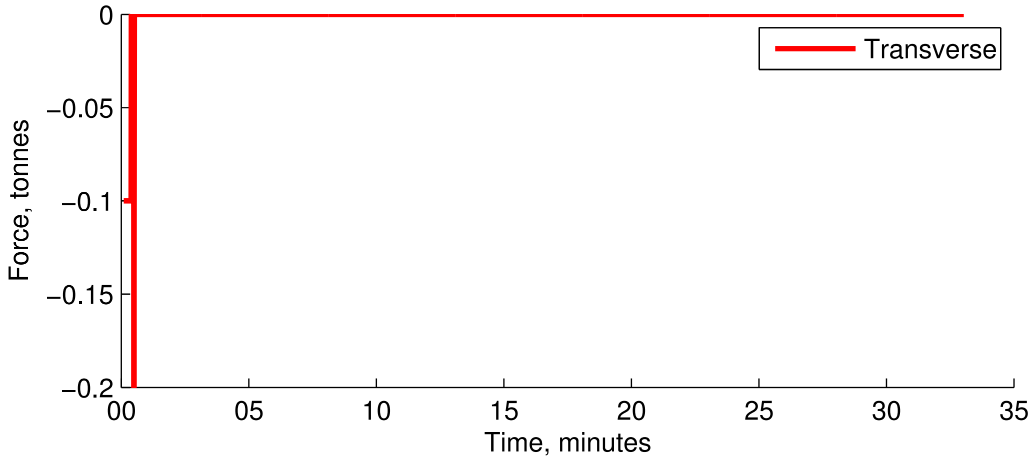


Figure 4-78: Transverse Bank Suction Force for Run 7

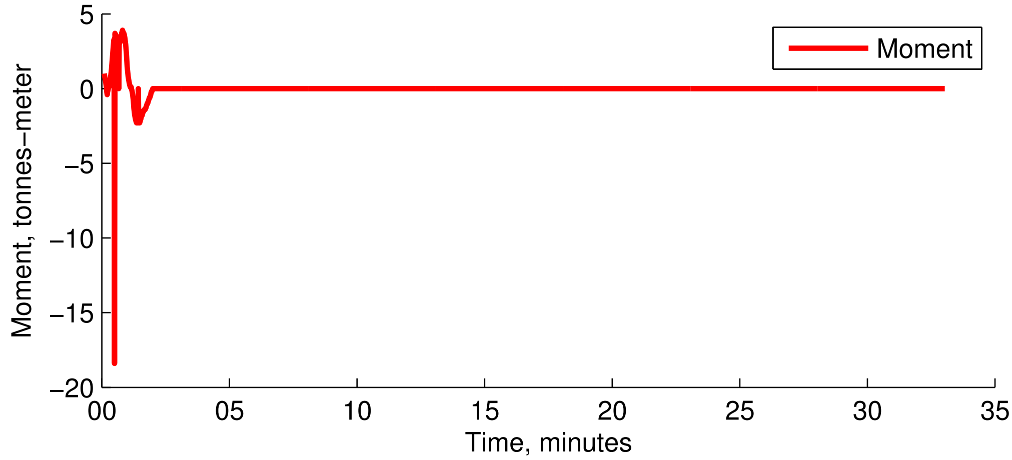


Figure 4-79: Bank Moment Force for Run 7

4.2.2 Run 8 – Inbound Winds from the West at 15 knots

Description:

Run 8 tests the inbound manoeuvre of the Azipod equipped cruise ship under wind speeds of 15 knots from the west. Manoeuvre intentions are identical to those of Run 7.

Main Propulsion:

Propulsion of both pods remains at or below 75 rpm, with short powerbursts (not exceeding 100 rpm) above this limit for limited durations.

Rudder:

During the approach channel transit, both bods are aligned parallel to the vessel's centreline. For the duration of the turn and berthing manoeuvre, the port pod is aligned with the vessel's centreline axis to provide longitudinal thrust while the starboard pod is aligned 90 degrees to this for transverse force generation.

Thruster:

Thruster usage is only used beyond 50% of total power for short bursts.

Wind force and moment:

While turning and backing into the harbour channel, transverse wind loads approach 40 tonnes while the wind force moment peaks at nearly 2000 tonnes-metres.

Clearances:

While backing down the harbour channel, the vessel is pushed slightly to starboard and close to the eastern limits of the channel; however, the vessel retains more than enough reserve power to control and counter this drift motion.

Bank force and moment:

Bank forces throughout the simulation were negligible.

Depth:

UKC during the simulation is always greater than 2 metres.

Overall:

The Azipod equipped cruise ship carries enough propulsion to counter the 15 knot wind speed and execute a well-controlled manoeuvre successfully. Furthermore, the proposed channel limits provide enough additional clearance for added safety.

Figure 4-80: Swept Path Plot for Run 8

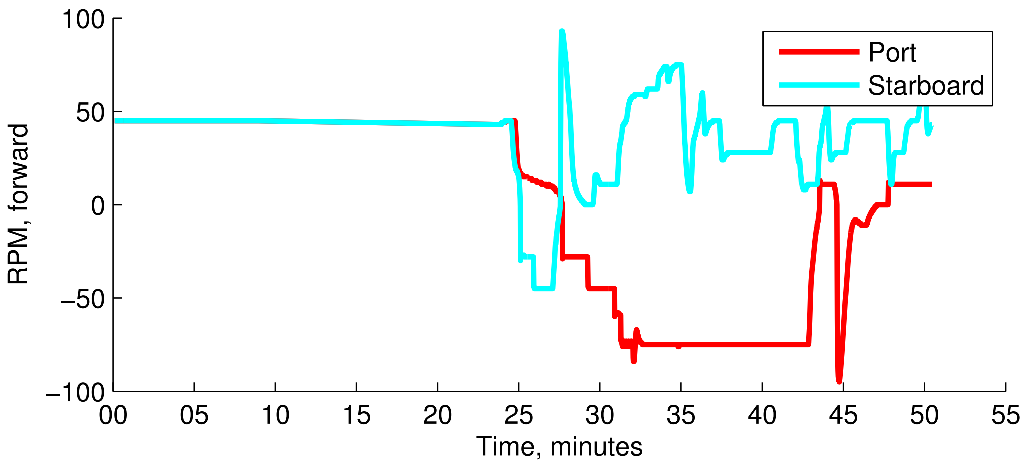


Figure 4-81: RPM Plot for Run 8

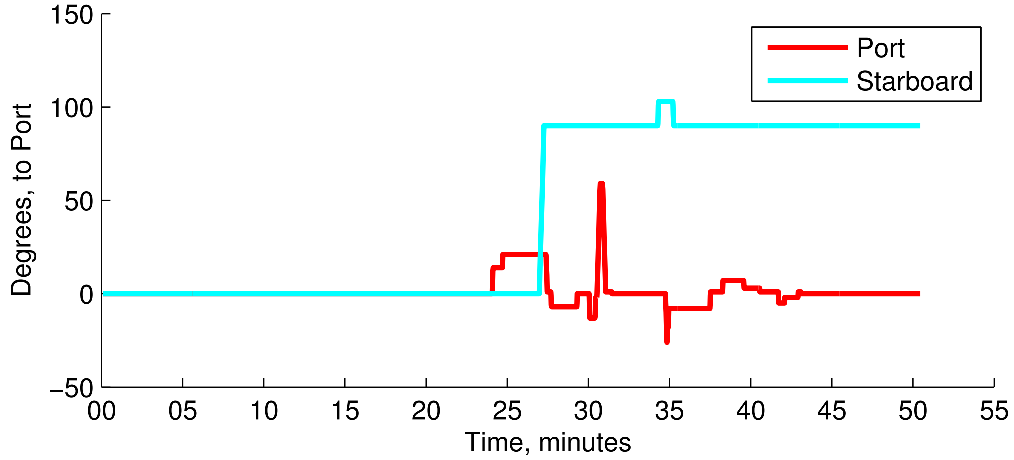


Figure 4-82: Rudder Plot for Run 8

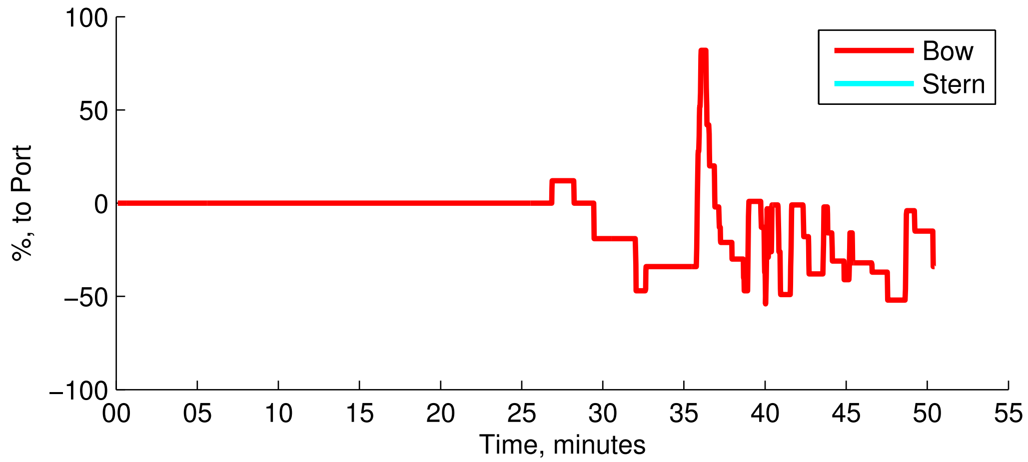


Figure 4-83: Thruster Usage Plot for Run 8

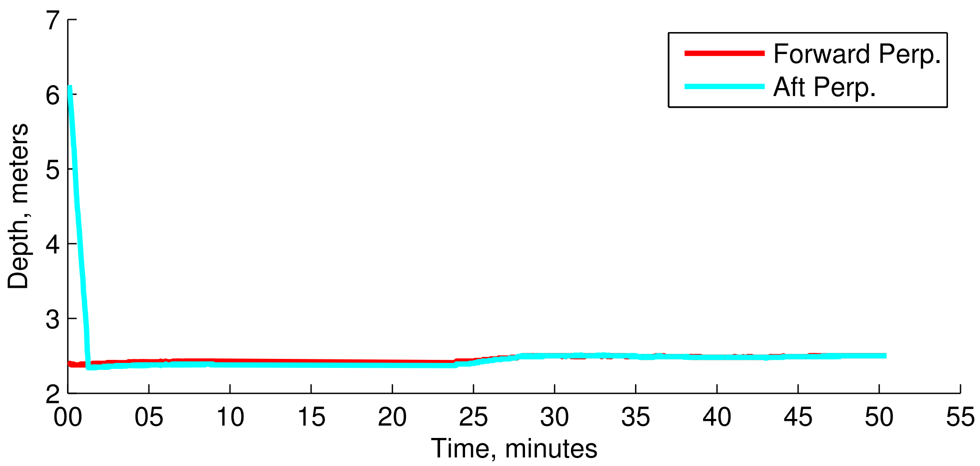


Figure 4-84: UKC Plot for Run 8

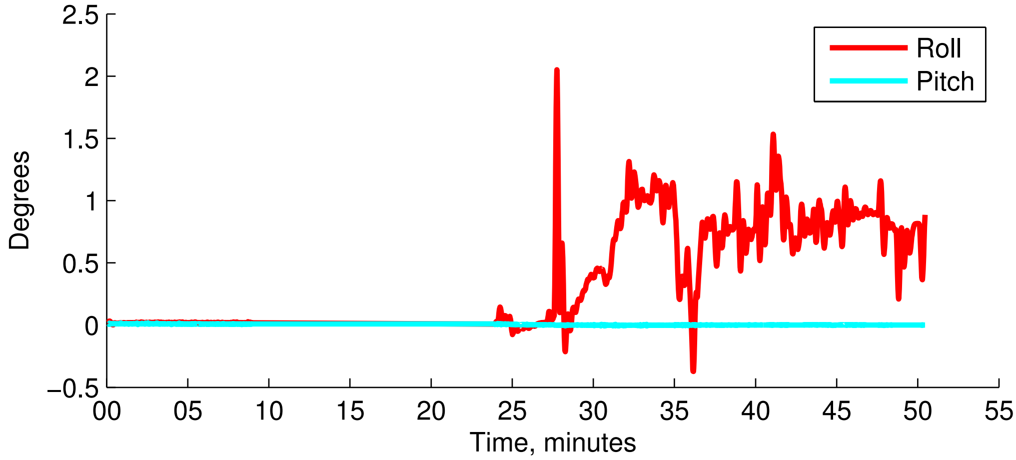


Figure 4-85: Roll and Pitch Plot for Run 8

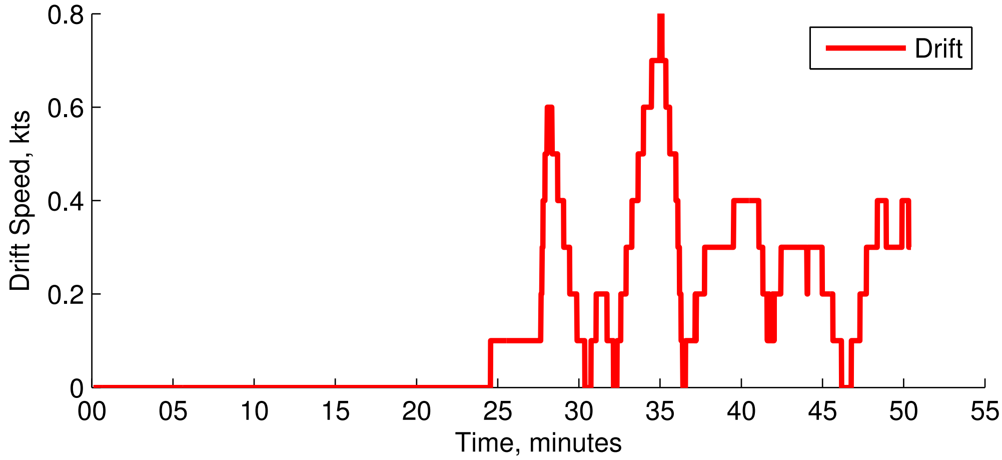


Figure 4-86: Drift Velocity Plot for Run 8

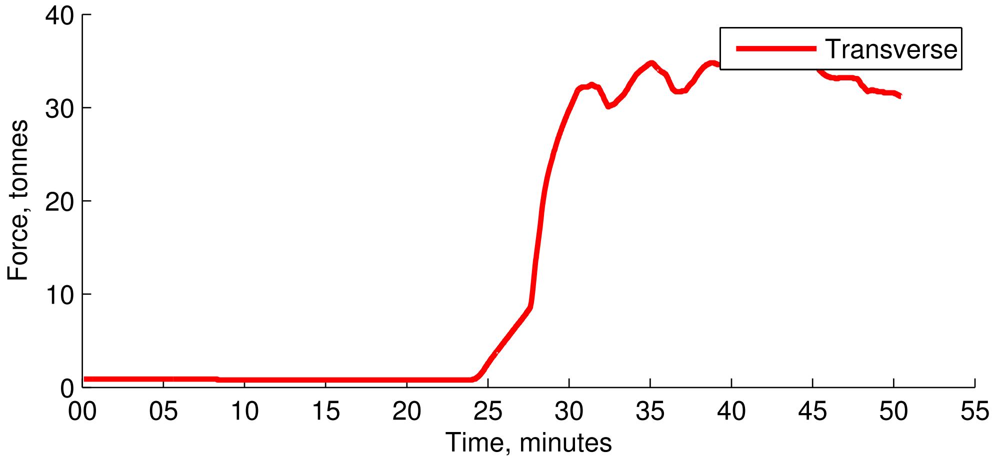


Figure 4-87: Transverse Wind Force Plot for Run 8

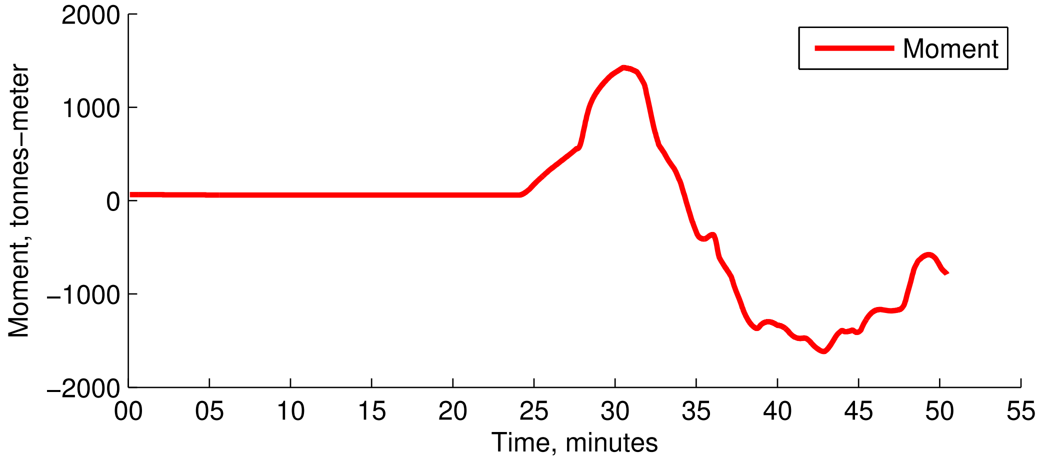


Figure 4-88: Wind Moment Force for Run 8

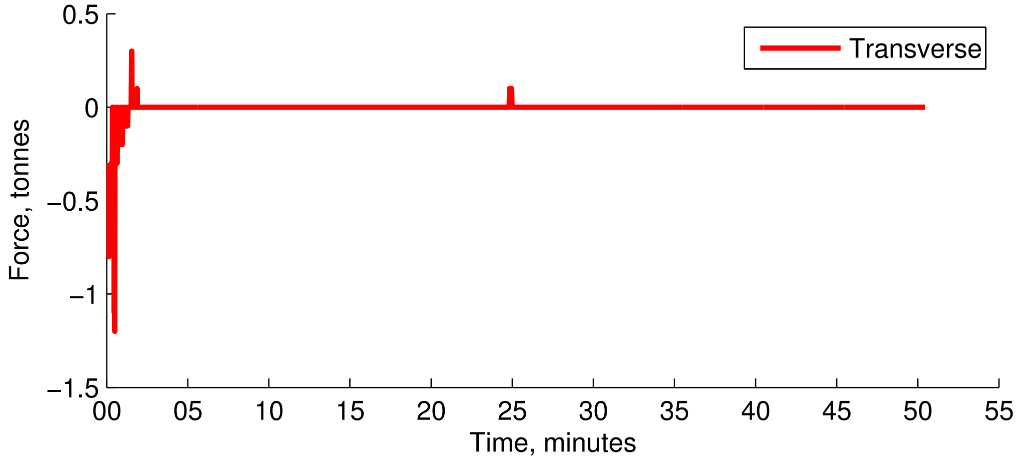


Figure 4-89: Transverse Bank Suction Force for Run 8

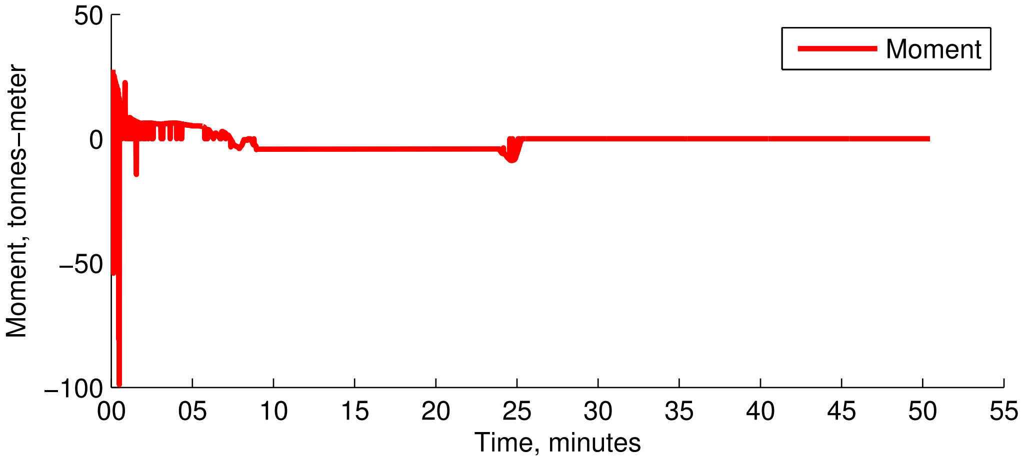


Figure 4-90: Bank Moment Force for Run 8

4.2.3 Run 9 – Inbound Winds from the Southwest at 15 knots

Description:

Manoeuvres with winds from the southwest at 15 knots are evaluated in run 9 for the Azipod equipped cruise ship. Manoeuvre intentions are identical to those of Run 7.

Main Propulsion:

Propulsion of both pods remains at or below 75 rpm, with short powerbursts (not exceeding 100 rpm) above this limit for limited durations.

Rudder:

During the approach channel transit, both pods are aligned nearly parallel to the vessel's centreline; just off enough to maintain the desired heading under the prescribed wind condition. For the duration of the turn and berthing manoeuvre, the port pod is aligned with the vessel's centreline axis to provide longitudinal thrust while the starboard pod is aligned 90 degrees to this for transverse force generation.

Thruster:

Thruster usage is only used beyond 50% of total power for short bursts.

Wind force and moment:

Transverse wind loading is around 40 tonnes (2000 tonnes-metre force moment) while the vessel transits the approach channel, but tapers to about 10 tonnes (1000 tonnes-metre force moment) at the ship changes heading to align with the harbour channel.

Clearances:

The vessel is able to transit along the proposed channel centrelines and maintain ample clearances to the channel extremes.

Bank force and moment:

Bank forces throughout the simulation were negligible.

Depth:

UKC during the simulation is always greater than 2 metres.

Overall:

Again, the propulsive capabilities of the Azipod equipped cruise ship are more than capable of countering the wind induced forces on the vessel and maintain desired track throughout the manoeuvre.

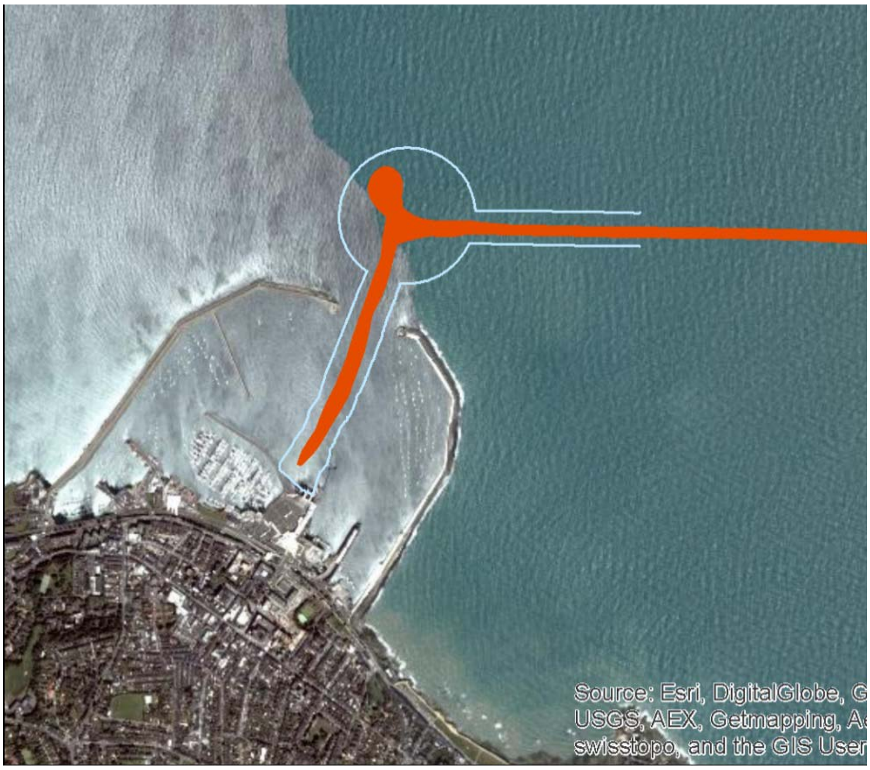


Figure 4-91: Swept Path Plot for Run 9

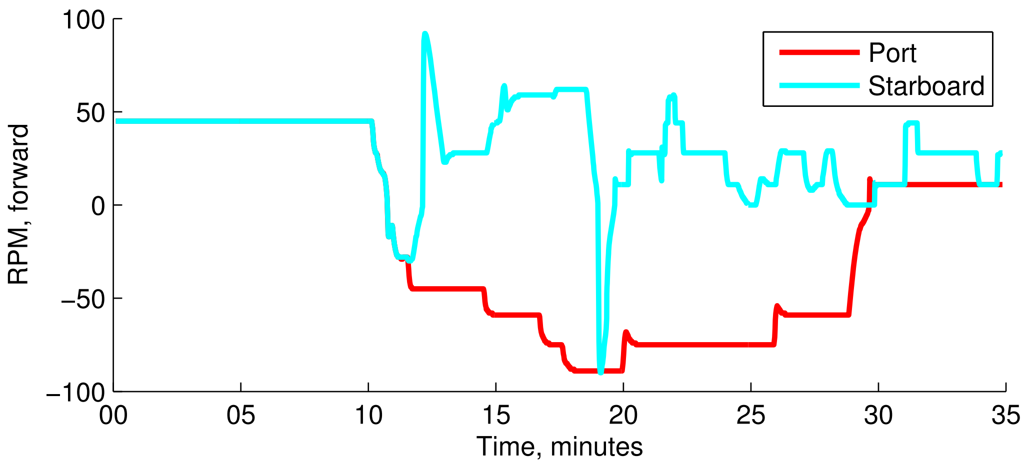


Figure 4-92: RPM Plot for Run 9

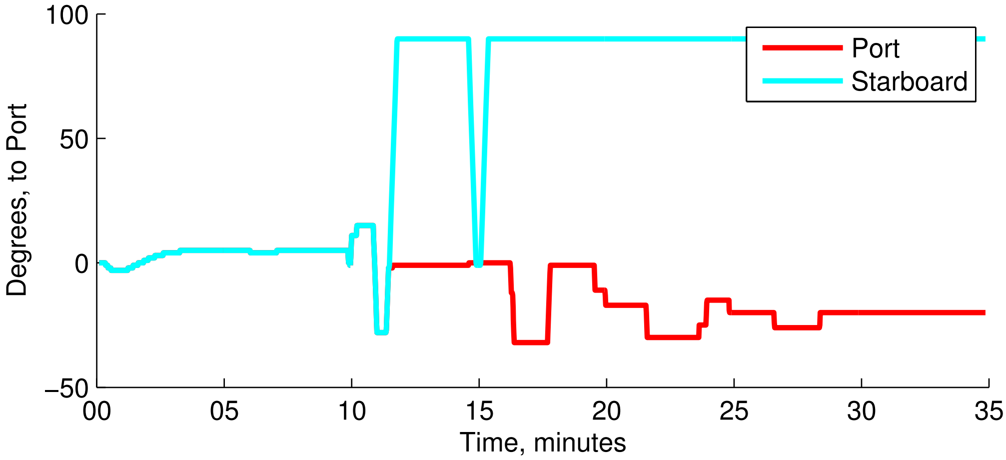


Figure 4-93: Rudder Plot for Run 9

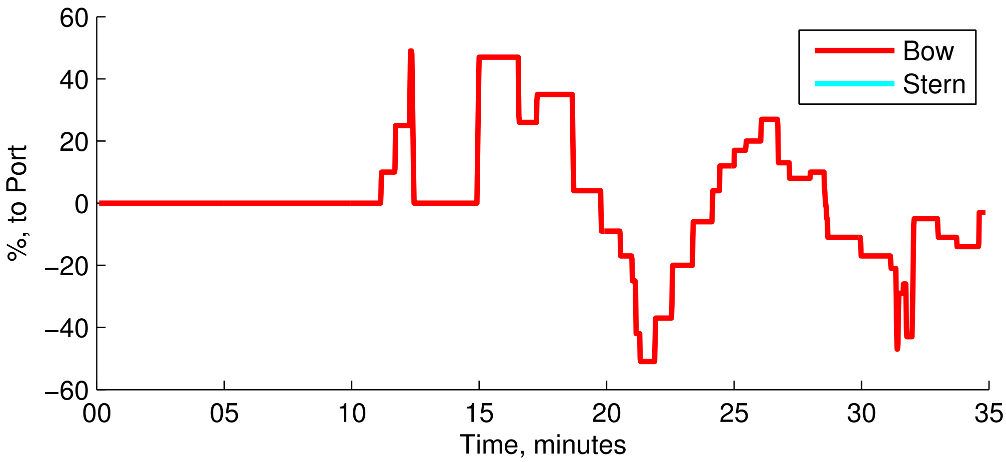


Figure 4-94: Thruster Usage Plot for Run 9

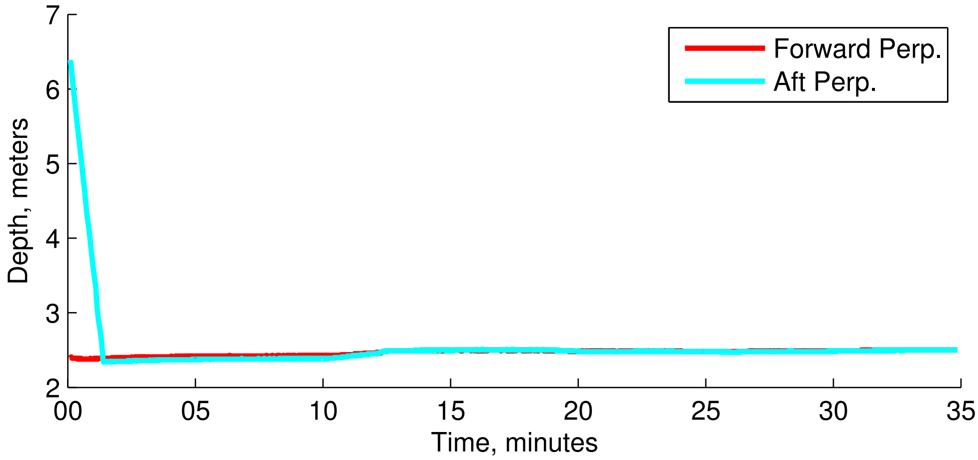


Figure 4-95: UKC Plot for Run 9

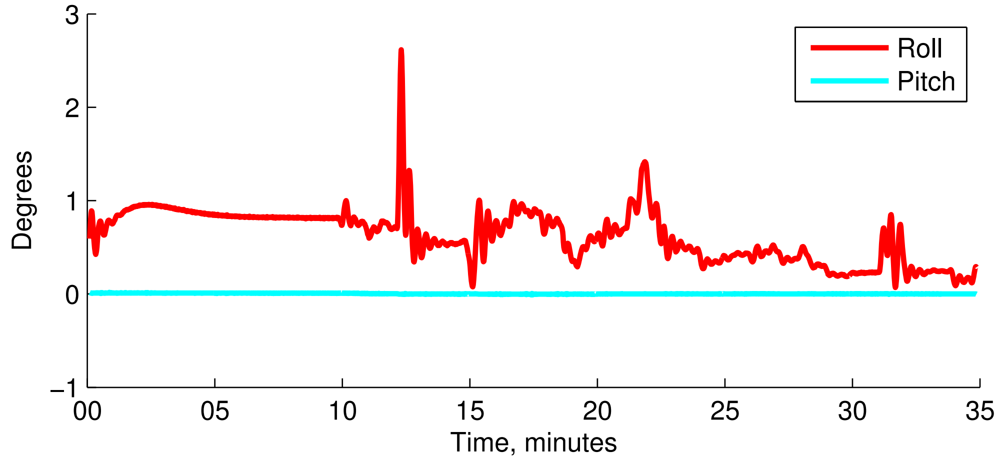


Figure 4-96: Roll and Pitch Plot for Run 9

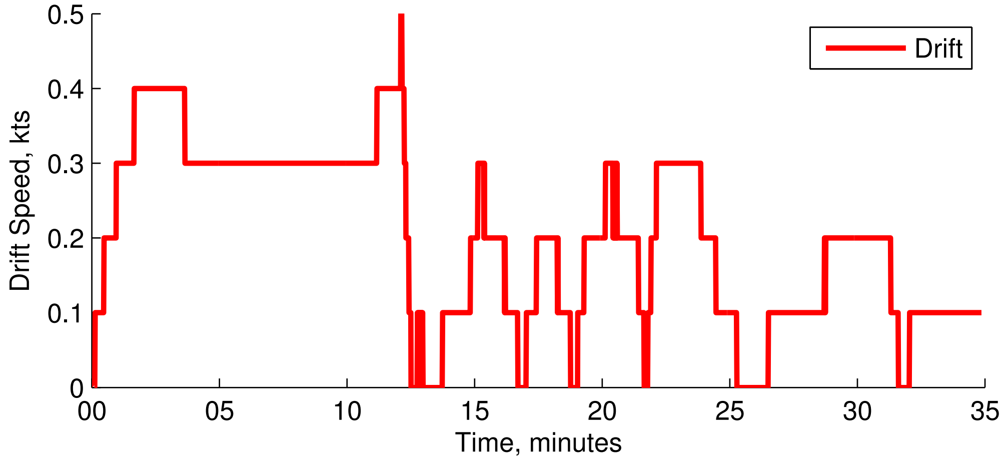


Figure 4-97: Drift Velocity Plot for Run 9

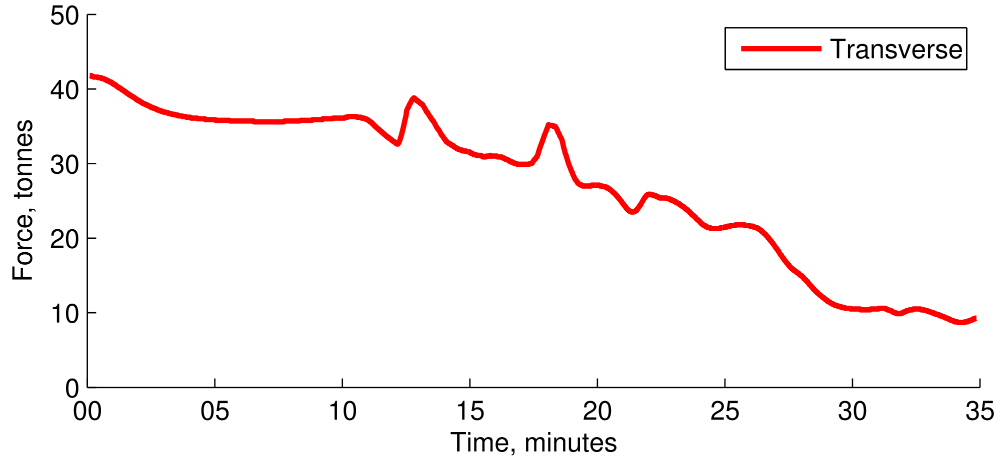


Figure 4-98: Transverse Wind Force Plot for Run 9

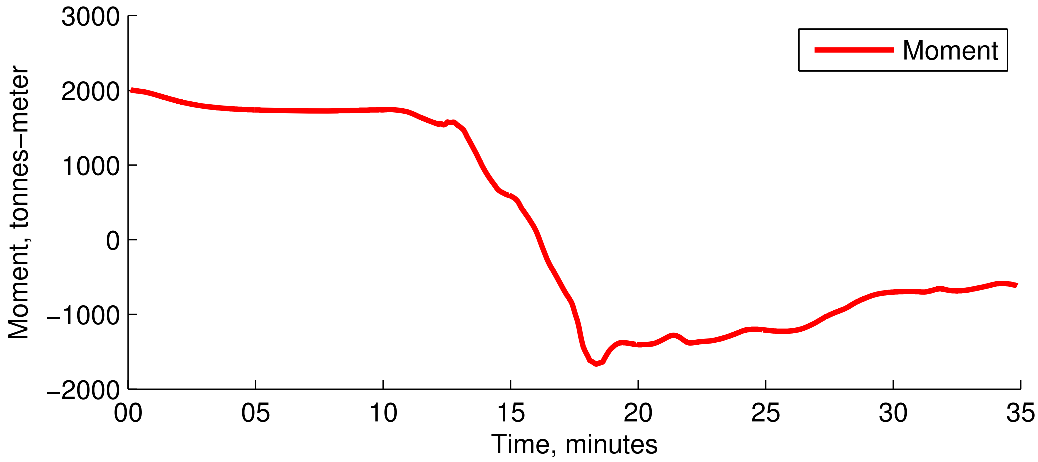


Figure 4-99: Wind Moment Force for Run 9

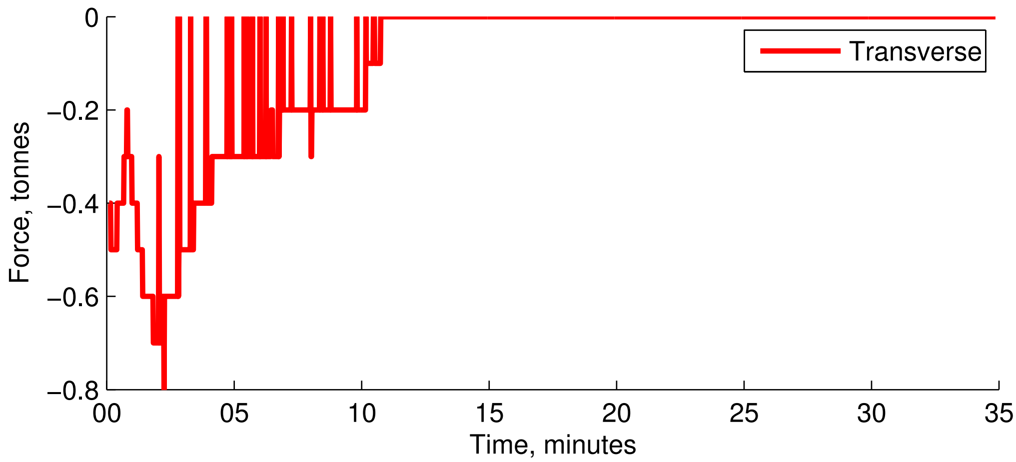


Figure 4-100: Transverse Bank Suction Force for Run 9

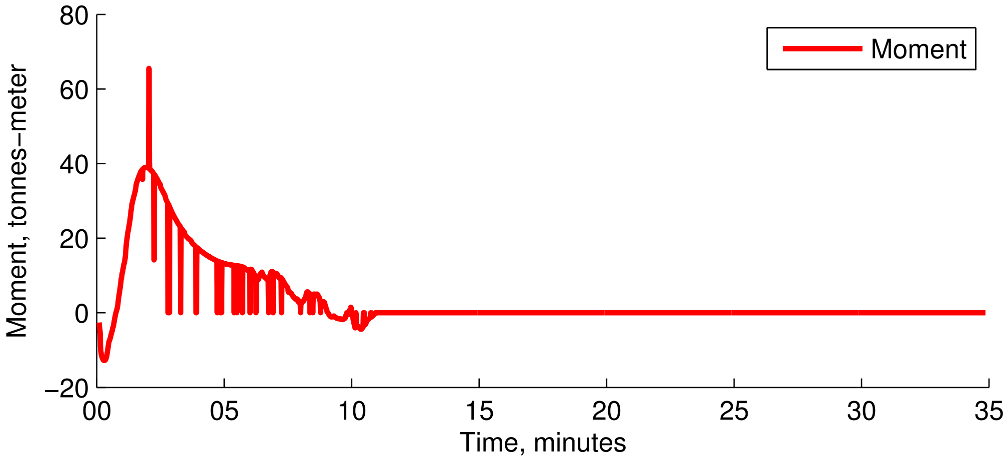


Figure 4-101: Bank Moment Force for Run 9

4.2.4 Run 10 – Inbound Winds from the South at 15 knots

Description:

15 knot winds from the south changed the swept path of the manoeuvre from previous runs, such that the pivot point of the vessel, as it swings the stern to port, is pushed further aft as the wind moment builds along the stern sections of the ship. Nevertheless, the manoeuvre intentions are identical to those of the previous runs.

Main Propulsion:

Propulsion of both pods remains at or below 75 rpm, with short powerbursts (not exceeding 100 rpm) above this limit for limited durations. The port pod is set at 75 rpm astern to build sternway against the southerly wind during the turn and reversing sections of the manoeuvre.

Rudder:

During the approach channel transit, both pods are aligned nearly parallel to the vessel's centreline; just off enough to maintain the desired heading under the prescribed wind condition. For the duration of the turn and berthing manoeuvre, the port pod is mostly aligned with the vessel's centreline axis to provide longitudinal thrust while the starboard pod is aligned 90 degrees to this for transverse force generation.

Thruster:

Bow thruster usage is fairly limited with short bursts up to 75% of total power during the initial turn and reverse sections of the manoeuvre.

Wind force and moment:

Wind force moment is about 2000 tonne-metres during the initial turn with transverse wind loading around 40 tonnes at the start of the simulation.

Clearances:

The vessel is able to transit along the proposed channel centrelines and maintain ample clearances to the channel extremes.

Bank force and moment:

Bank forces throughout the simulation were negligible.

Depth:

UKC during the simulation is always greater than 2 metres.

Overall:

Again, the propulsive capabilities of the Azipod equipped cruise ship are more than capable of countering the wind induced forces on the vessel and maintain desired track throughout the manoeuvre.

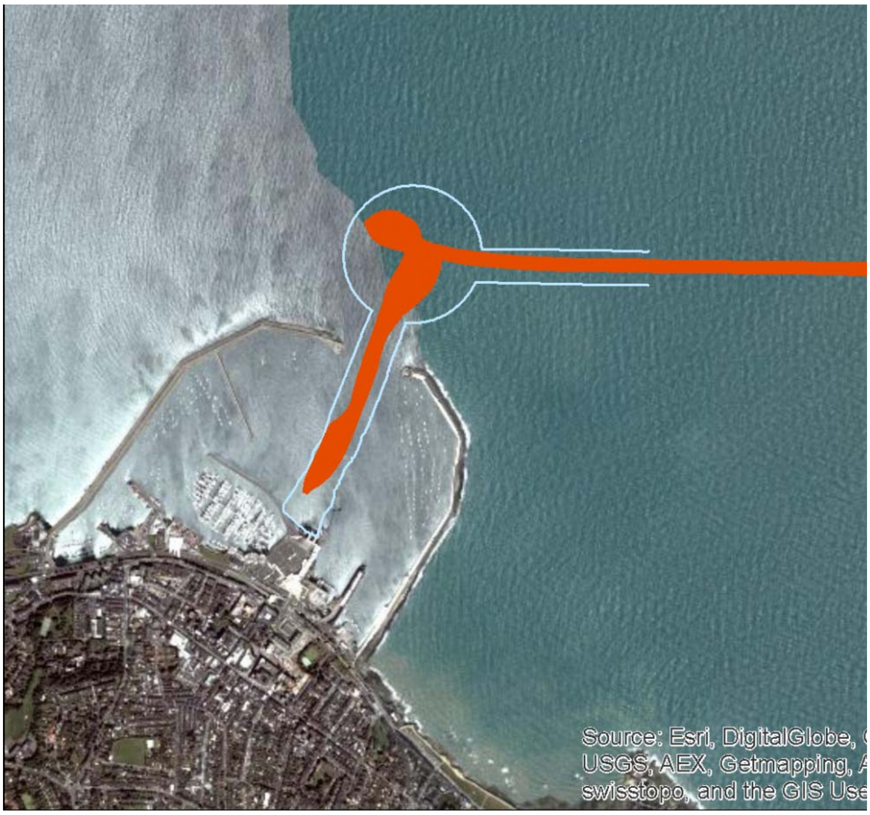


Figure 4-102: Swept Path Plot for Run 10

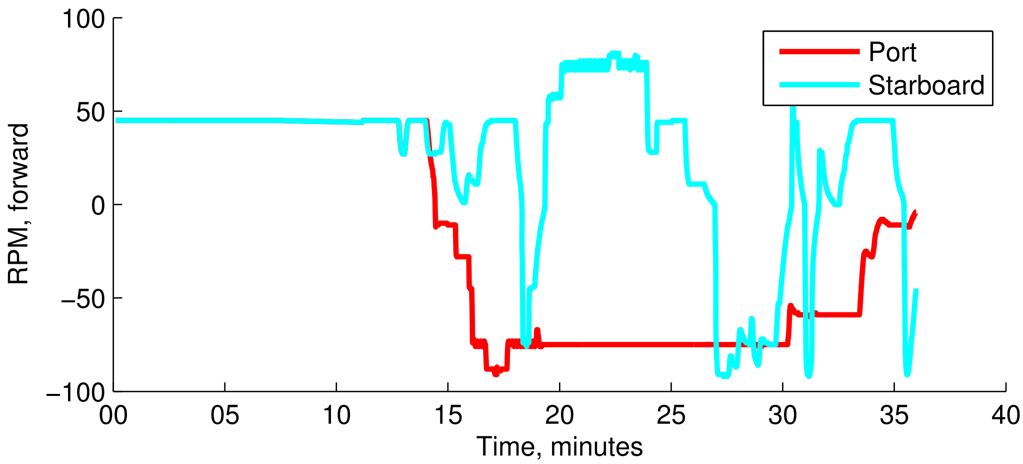


Figure 4-103: RPM Plot for Run 10

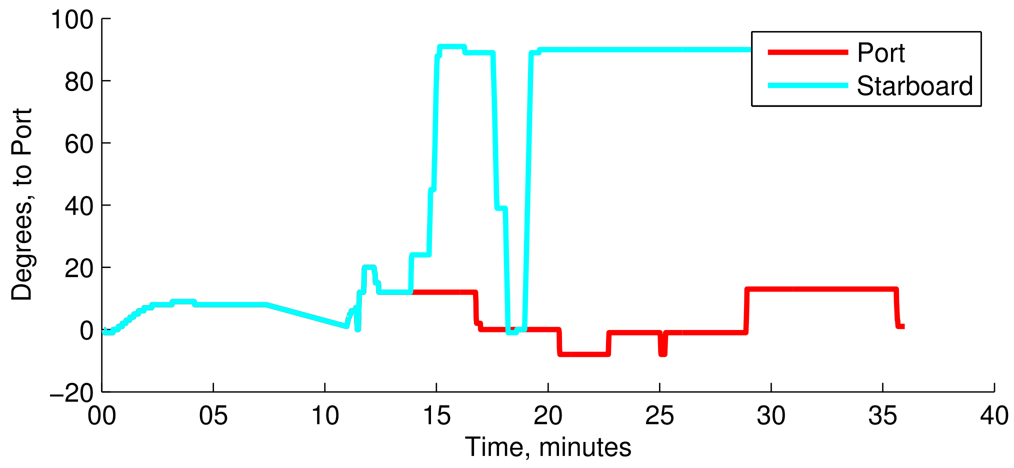


Figure 4-104: Rudder Plot for Run 10

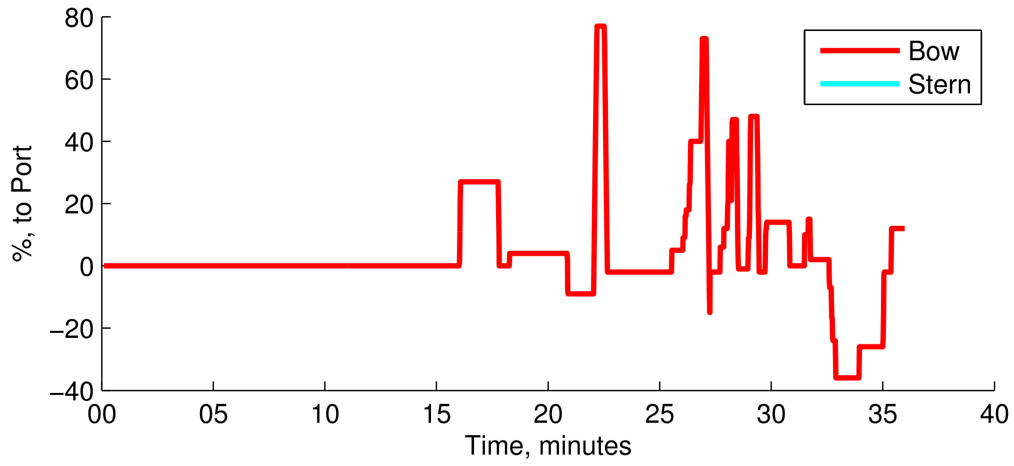


Figure 4-105: Thruster Usage Plot for Run 10

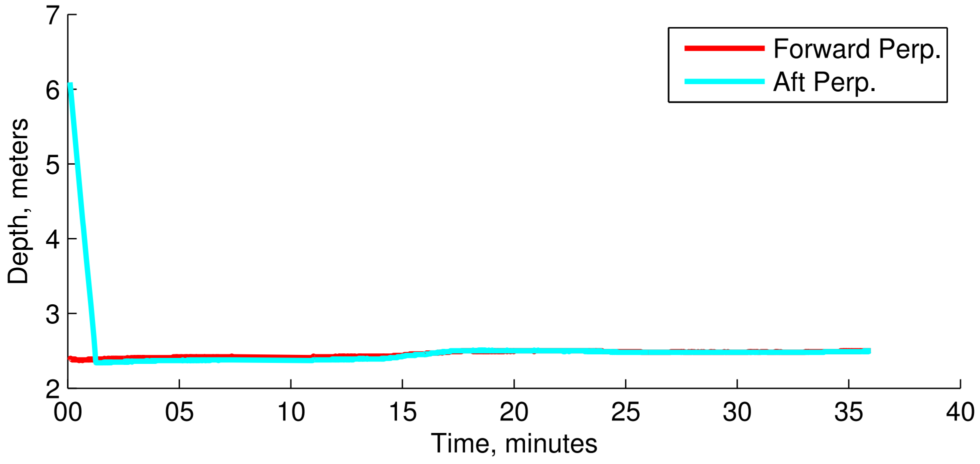


Figure 4-106: UKC Plot for Run 10

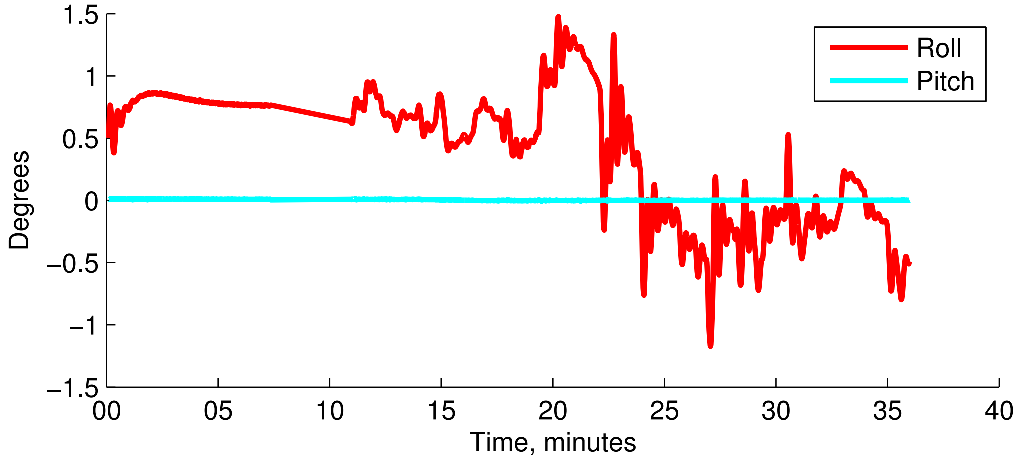


Figure 4-107: Roll and Pitch Plot for Run 10

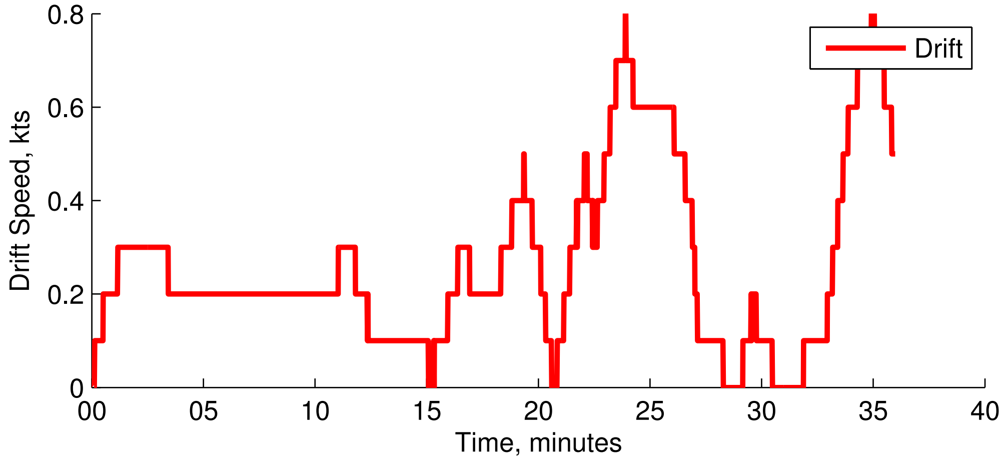


Figure 4-108: Drift Velocity Plot for Run 10

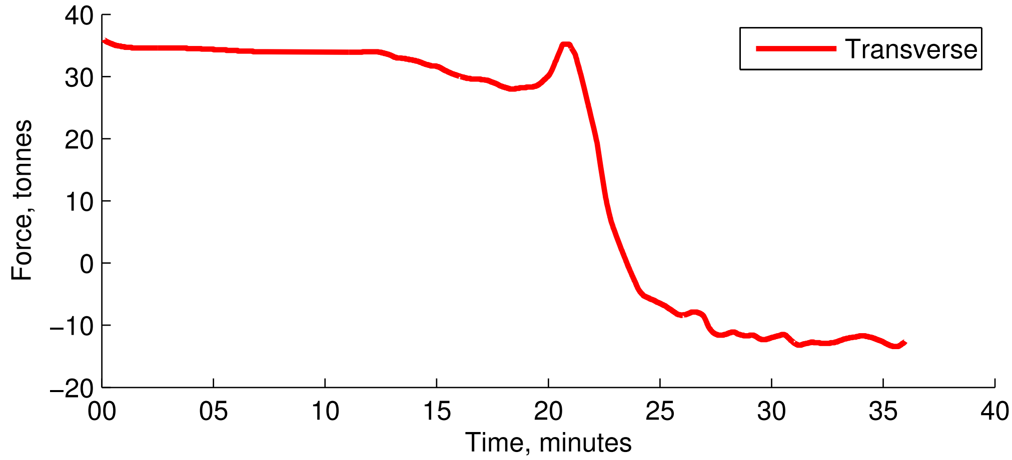


Figure 4-109: Transverse Wind Force Plot for Run 10

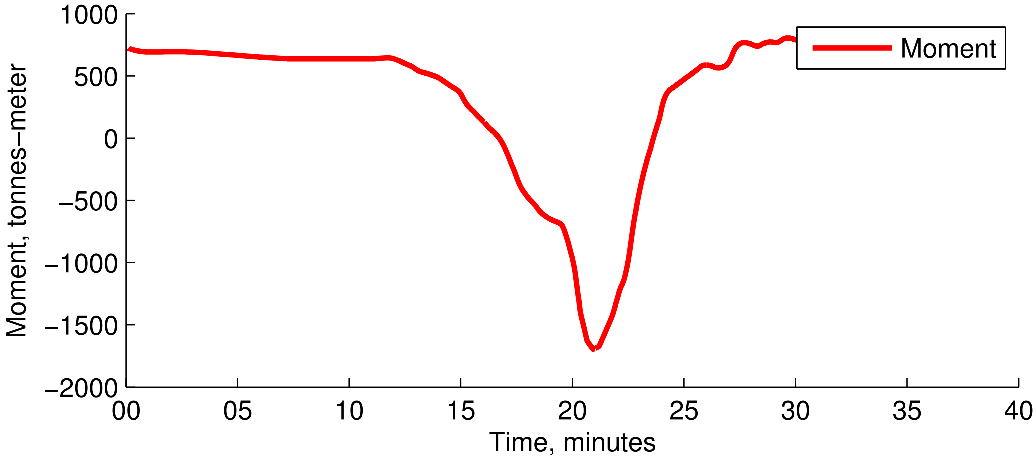


Figure 4-110: Wind Moment Force for Run 10

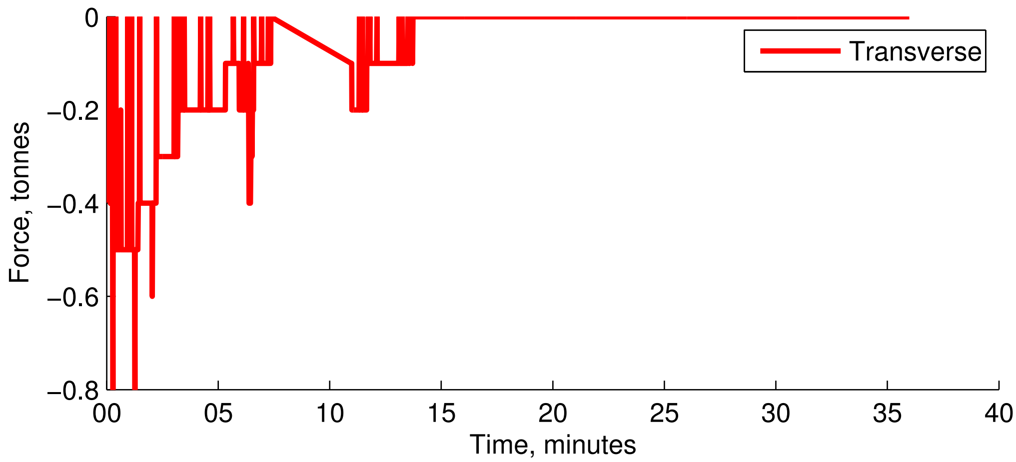


Figure 4-111: Transverse Bank Suction Force for Run 10

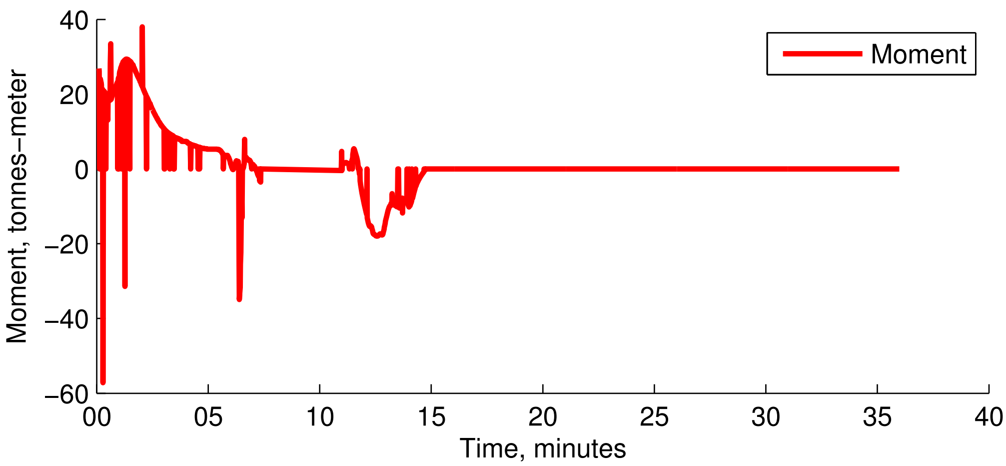


Figure 4-112: Bank Moment Force for Run 10

4.2.5 Run 11 – Inbound Winds from the West at 25 knots

Description:

To demonstrate the propulsive abilities of the Azipod equipped cruise ship, an inbound manoeuvre was repeated with winds from the west at 25 knots. Similar to previous runs, all intentions of the manoeuvre were based off of those of run 7 above.

Main Propulsion:

Maintaining headway into the 25 knot wind required the main propulsion of the vessel to exceed 100 rpm for a short duration through the approach channel. The initial turning and backing of the vessel also required maintaining around 100 rpm on both the port and starboard pods.

Rudder:

During the approach channel transit, both pods are aligned nearly parallel to the vessel's centreline; just off enough to maintain the desired heading under the prescribed wind condition. For the duration of the turn and berthing manoeuvre, the port pod is aligned with the vessel's centreline axis to provide longitudinal thrust (deviating periodically for additional transverse thrust supply) while the starboard pod is aligned 90 degrees to this for transverse force generation.

Thruster:

Bow thruster usage is maintained at 50% during most of the turning and backing manoeuvre with short periodic bursts to 75%.

Wind force and moment:

Transverse wind loading peaks around 90 tonnes as the ship presents more broadside to the wind and the resisting wind force moment builds to 4000 tonne-metres during the early stages of the initial turn to the harbour channel.

Clearances:

The vessel is able to transit along the proposed channel centrelines and maintain ample clearances to the channel extremes. At one point, the ship approaches the eastern intersection of the turning basin and the harbour channel, but maintains enough transverse propulsive force to move laterally against the wind and back along the desired centreline track.

Bank force and moment:

Bank forces throughout the simulation were negligible.

Depth:

UKC during the simulation is always greater than 2 metres.

Overall:

Though higher engine settings are required throughout the manoeuvre, this simulation demonstrated the capabilities of an Azipod equipped cruise ship to counteract adverse weather conditions and it's superior manoeuvrability when compared to its fixed propeller counterpart.

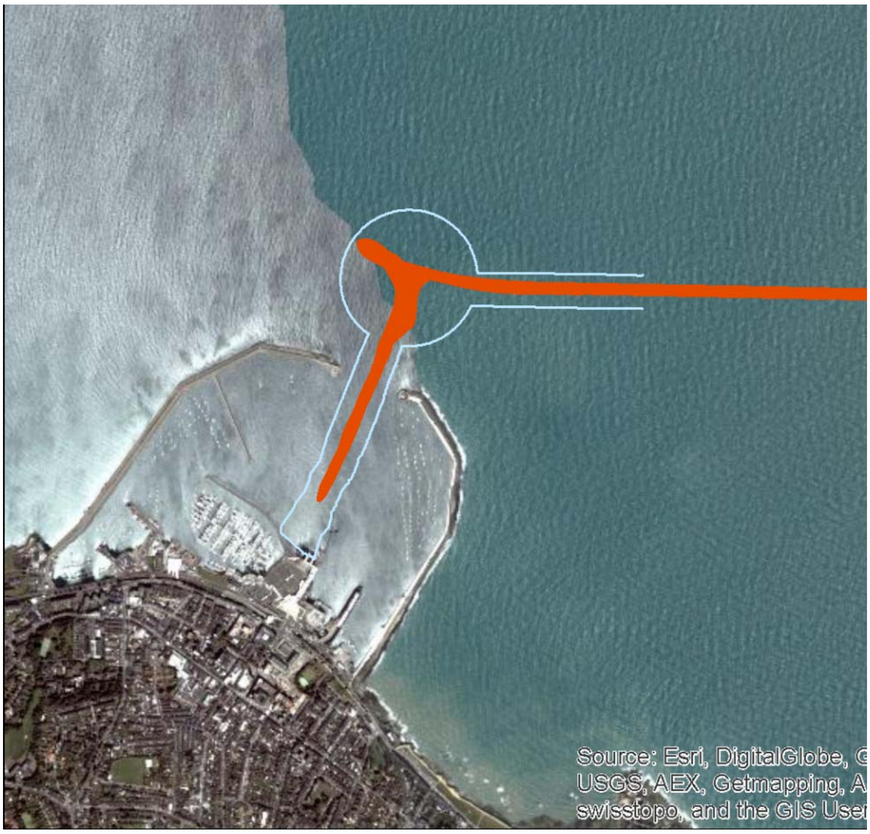


Figure 4-113: Swept Path Plot for Run 11

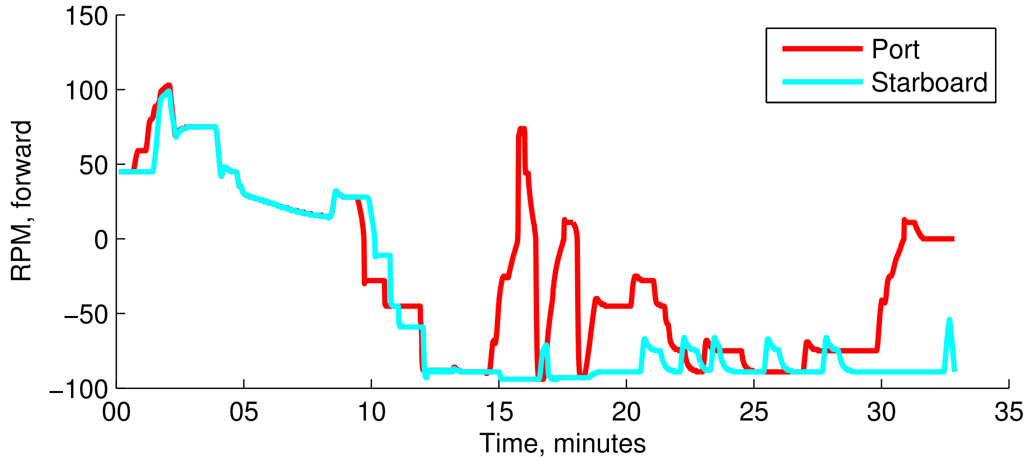


Figure 4-114: RPM Plot for Run 11

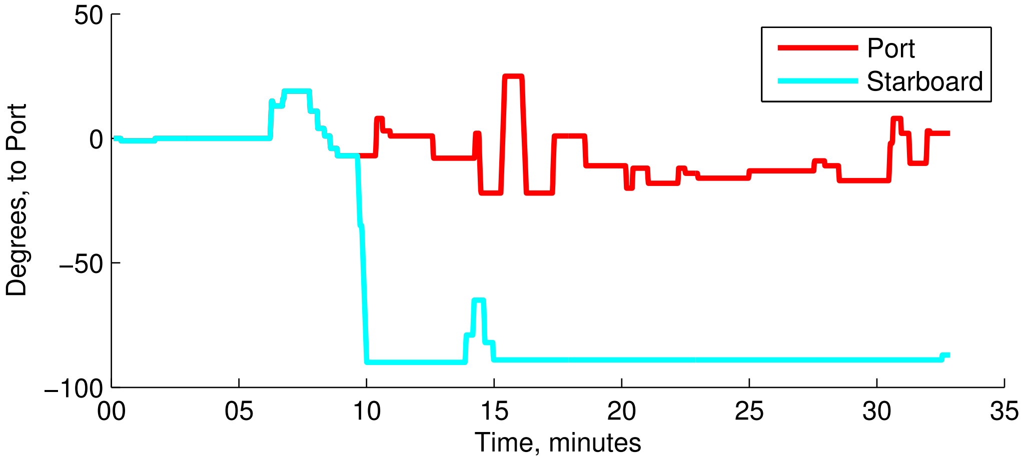


Figure 4-115: Rudder Plot for Run 11

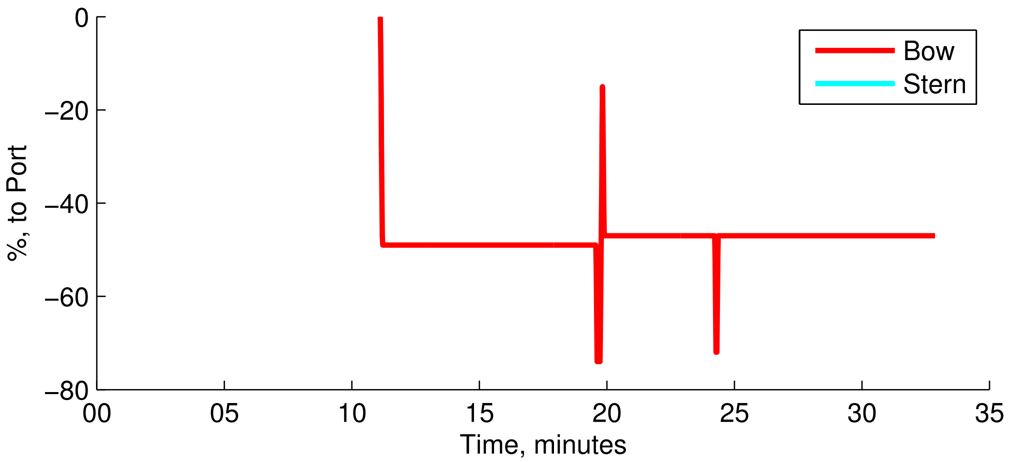


Figure 4-116: Thruster Usage Plot for Run 11

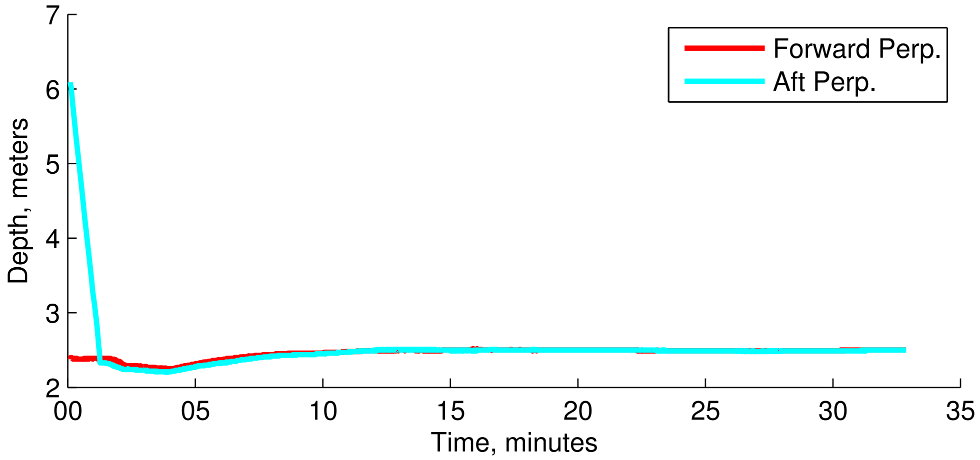


Figure 4-117: UKC Plot for Run 11

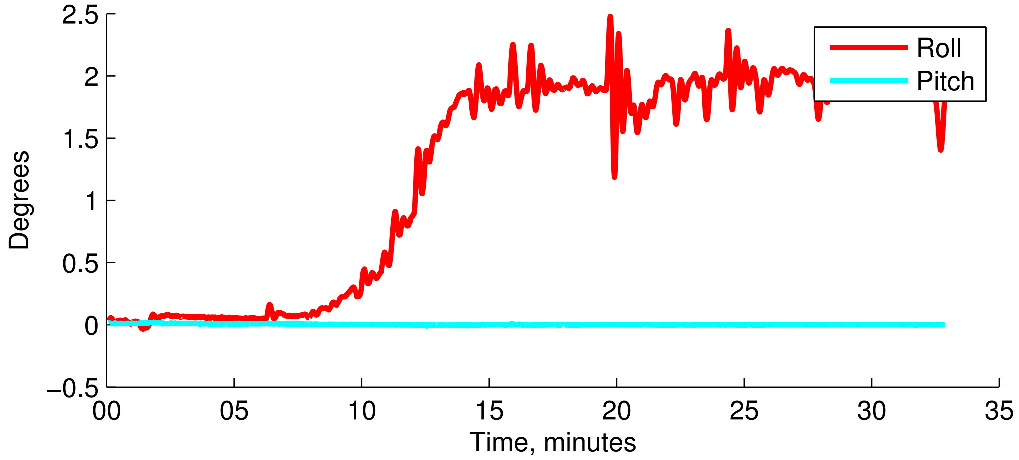


Figure 4-118: Roll and Pitch Plot for Run 11

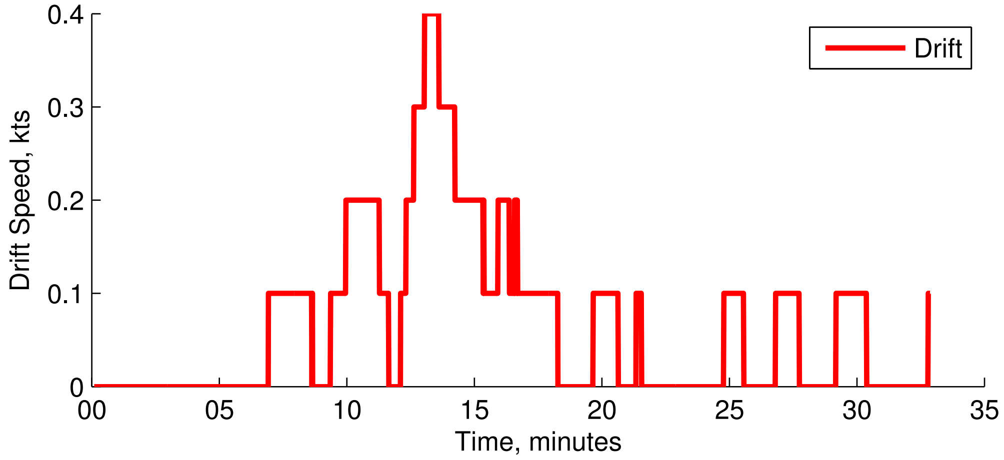


Figure 4-119: Drift Velocity Plot for Run 11

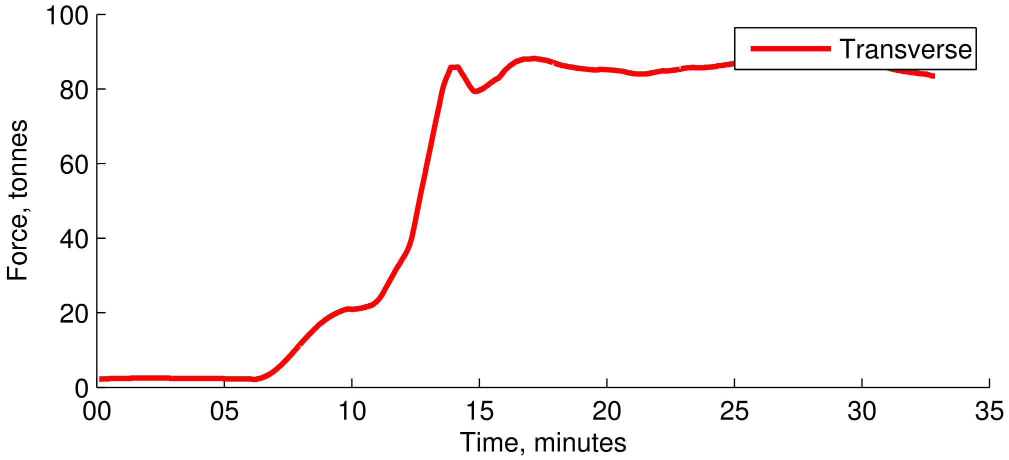


Figure 4-120: Transverse Wind Force Plot for Run 11

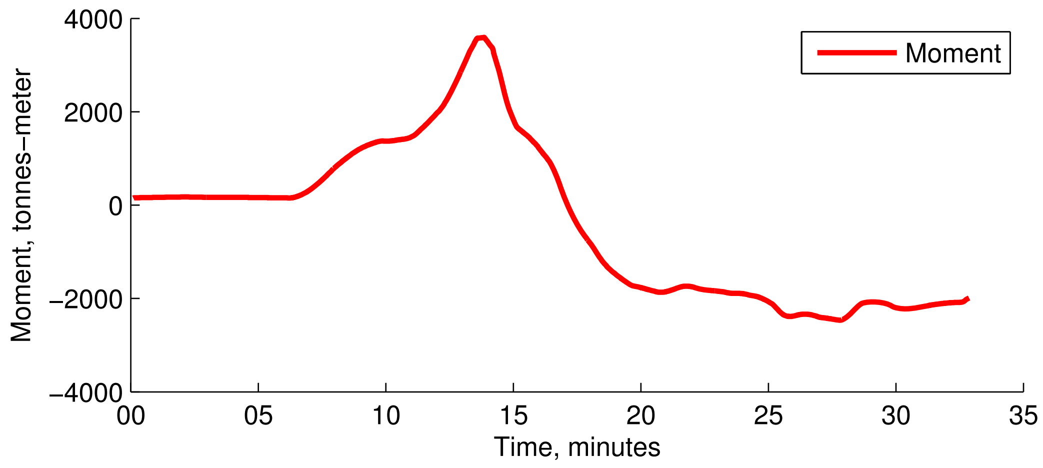


Figure 4-121: Wind Moment Force for Run 11

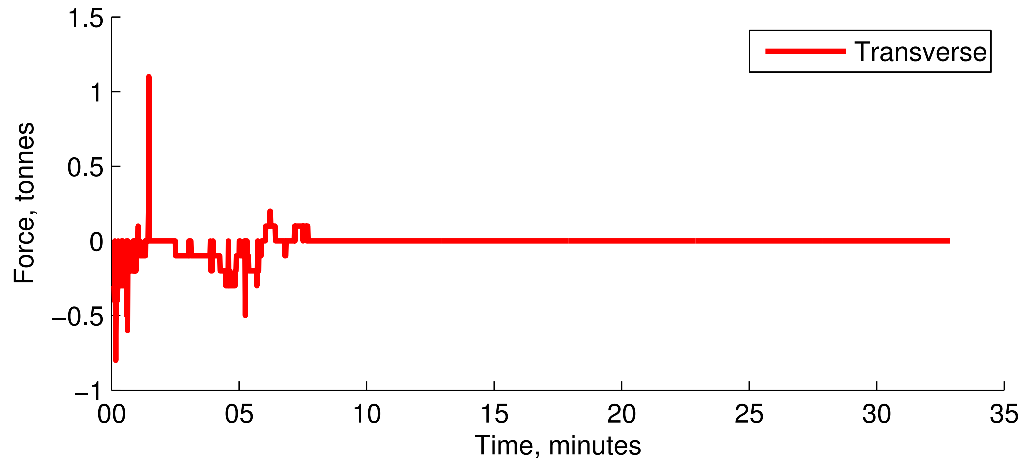


Figure 4-122: Transverse Bank Suction Force for Run 11

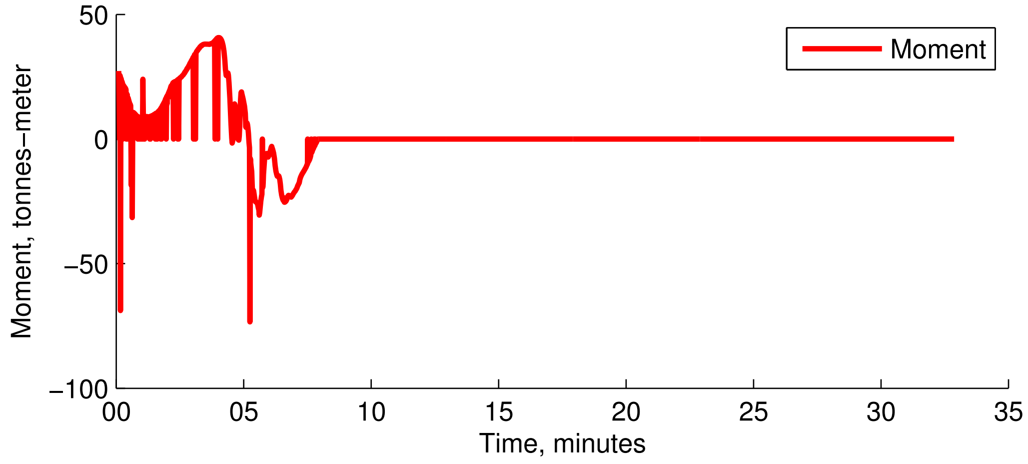


Figure 4-123: Bank Moment Force for Run 11

5. CONCLUSIONS AND RECOMMENDATIONS

Further analysis and design into this proposal warrants more detailed investigation of the metocean conditions in and around Dun Laoghaire harbour. Wind data collected from nearby Dublin International Airport indicates predominant hourly sustained wind speeds around 15 knots, which is at the modelled limit for the large, fixed-propeller cruise ship. Furthermore, navigational analysis to date has been conducted with no provision for currents within the harbour and is based on limited information concerning the wave environment around the site. It is recommended that local data collection is either conducted or retrieved from another source at the site to develop a more accurate understanding of wind, wave and current fields.

Simulations assessed the viability of a 120 metre channel established along the centreline of the harbour entrance. Based on observed historic vessel movements within the harbour, it is recognised the berthed cruise ships will amend existing traffic patterns. Furthermore, this analysis was conducted assuming a single berth location close to the existing HSS berth at the southwestern end of the proposed harbour channel. Should these characteristics be modified as terminal layout and design becomes more refined or changed, simulations should be performed to revaluate the effects of these changes from a navigational standpoint.

The dimensions of the cruise ship identified in '*Cruise Terminal Design Criteria*' issued by Moffatt and Nichol December 4, 2013 would amend navigational access to the marinas in the west of the harbour (reflecting proposed changes to the areas allocated for swinging moorings.

Results of these navigation simulations reveal that the proposed channel layouts are satisfactory with some proposed improvements (Figure 5-1). Proposed improvements involve tapering the intersection of the approach and harbour channels at the intersection with the turning basin. These modifications allow for more channel clearance while the cruise ships turn to or from the harbour. Setting the turning basin diameter at 500 metres was determined to be sufficient under the tested wind limits.

It is noted that bank suction forces are very dependent on vessel speed and acceleration. Larger suction forces at the initial stages of the simulations correspond to time steps with elevated vessel velocity and acceleration through the water (relative to the remainder of the simulation). While the bank is higher in shallower water, the vessel is moving much slower and therefore bank suction effects are minimized.

Figure 5-1: Combined Swept Paths of all of the Simulations with Proposed Channel Improvements

As noted in the report, wind limits for vessel approach and departure will vary depending on the size and propulsive characteristics of the cruise ship. It should be stated again, that this report assumed all manoeuvres were simulated unassisted by tugs and were evaluated based on the qualities of the simulated ship alone. The use of tugs could improve turning manoeuvres outside the breakwaters, but there is limited room for tug manoeuvring through the harbour entrance. The collected AIS records show that manoeuvres of ship in this class are rarely assisted by tugs. Vessels equipped with Azipod propulsion systems have a distinct advantage in the predominant wind climate of Dun Laoghaire.

Results presented in this report are derived from an engineering standpoint; further simulations of more refined channel and terminal layouts are warranted with the input of local pilots and harbour authorities.

6. REFERENCES

USACE, 2006. “Hydraulic Design of Deep-Draft Navigation Projects,” *Engineering Manual 1110-2-1613.* Washington, DC.

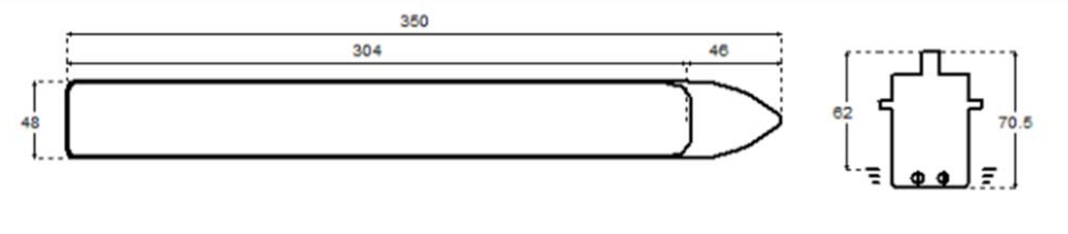
PIANC, 1997. “Approach Channels A Guide For Design,” *PTC II-30*. Brussels, Belgium.

APPENDIX A

PILOT CARDS OF MODELED VESSELS

PILOT CARD					
Ship name	Passenger cruise ship 6 (Dis.71222t) TRANSAS 2.31.1.0 *			Date	12.01.2012
IMO Number	N/A	Call Sign	N/A	Year built	N/A
Load Condition	Full load				
Displacement	71222 tones		Draft forward	8.5 m / 27 ft 11 in	
Deadweight	11020 tonnes		Draft forward extreme	8.5 m / 27 ft 11 in	
Capacity			Draft after	8.5 m / 27 ft 11 in	
Air draft	62 m / 203 ft 11 in		Draft after extreme	8.5 m / 27 ft 11 in	

Ship's Particulars			
Length overall	350 m	Type of bow	Bulbous
Breadth	48 m	Type of stern	Transom
Anchor Chain(Port)	13 shackles		
Anchor Chain(Starboard)	12 shackles		
Anchor Chain(Stern)	N/A shackles	(1 shackle =27.5 m / 15 fathoms)	



Steering characteristics			
Steering device(s) (type/No.)	Normal balance rudder / 2	Number of bow thrusters	3
Maximum angle	35	Power	3000 kW / 3000 kW / 3000 kW
Rudder angle for neutral effect	0 degrees	Number of stern thrusters	2
Hard over to over(2 pumps)	26 seconds	Power	3000 kW / 3000 kW
Flanking Rudder(s)	0	Auxiliary Steering Device(s)	

Stopping			Turning circle	
Description	Full Time	Head reach	Ordered Engine: 100%, Ordered rudder: 35 degrees	
FAH to FAS	391.6 s	7.37 cbls	Advance	4.32 cbls
HAH to HAS	557.6 s	6.83 cbls	Transfer	1.52 cbls
SAH to SAS	827.6 s	6.66 cbls	Tactical diameter	3.73 cbls

Main Engine(s)			
Type of Main Engine	Slow speed diesel	Number of propellers	2
Number of Main Engine(s)	2	Propeller rotation	Outward
Maximum power per shaft	2 x 26200 kW	Propeller type	FPP
Astern power	50 % ahead	Min. RPM	20.03
Time limit astern	N/A	Emergency FAH to FAS	12.9 seconds

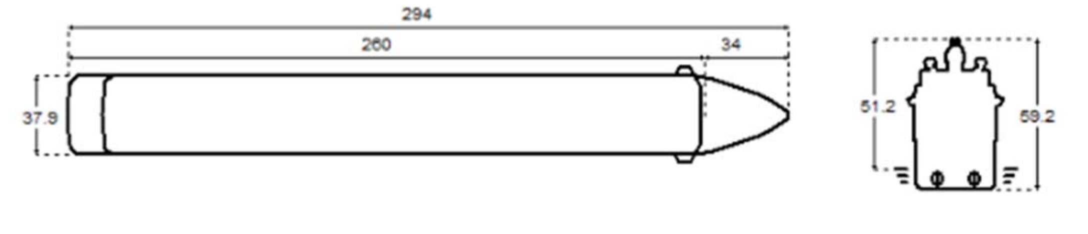
Engine Telegraph Table

Engine order	Speed, knots	Engine power, kW	RPM	Pitch ratio
Full Sea Ahead	23.7	24350	140	1.07
Full Ahead	15.2	6612	90	1.07
Half Ahead	10.2	2038	60	1.07
Slow Ahead	6.8	654	40.1	1.07
Dead Slow Ahead	3.3	111	20	1.07
Dead Slow Astern	-1.6	183	-20.3	1.07
Slow Astern	-3.2	1186	-40.3	1.07
Half Astern	-4.8	3874	-60.5	1.07
Full Astern	-7.2	12736	-90.6	1.07

Figure A-1: Pilot Card for the Fixed Propeller Cruise Ship

PILOT CARD					
Ship name	Passenger cruise ship 10 3.0.2.0 *			Date	28.11.2012
IMO Number	N/A	Call Sign	N/A	Year built	N/A
Load Condition	LC1				
Displacement	44000 tones		Draft forward	8 m / 26 ft 3 in	
Deadweight	N/A tonnes		Draft forward extreme	8 m / 26 ft 3 in	
Capacity			Draft after	8 m / 26 ft 3 in	
Air draft	51.2 m / 168 ft 5 in		Draft after extreme	8 m / 26 ft 3 in	

Ship's Particulars			
Length overall	294 m	Type of bow	Bulbous
Breadth	37.9 m	Type of stem	U-shaped
Anchor(s) (No./types)	2 (PortBow / StbdBow)		
No. of shackles	15 / 15		(1 shackle =27.5 m / 15 fathoms)
Max. rate of heaving, m/min	18 / 18		



Steering characteristics			
Steering device(s) (type/No.)	Z-Drive / 2	Number of bow thrusters	3
Maximum angle	35	Power	2360 kW / 2360 kW / 2360 kW
Rudder angle for neutral effect	0 degrees	Number of stern thrusters	N/A
Hard over to over(2 pumps)	14 seconds	Power	N/A
Flanking Rudder(s)	0	Auxiliary Steering Device(s)	Auxiliary Steering Device(s): N/A

Stopping			Turning circle	
Description	Full Time	Head reach	Ordered Engine: 100%, Ordered rudder: 35 degrees	
FAH to FAS	353.6 s	9.52 cbls	Advance	3.61 cbls
HAH to HAS	304.6 s	6.16 cbls	Transfer	1.5 cbls
SAH to SAS	401.6 s	4.75 cbls	Tactical diameter	3.75 cbls

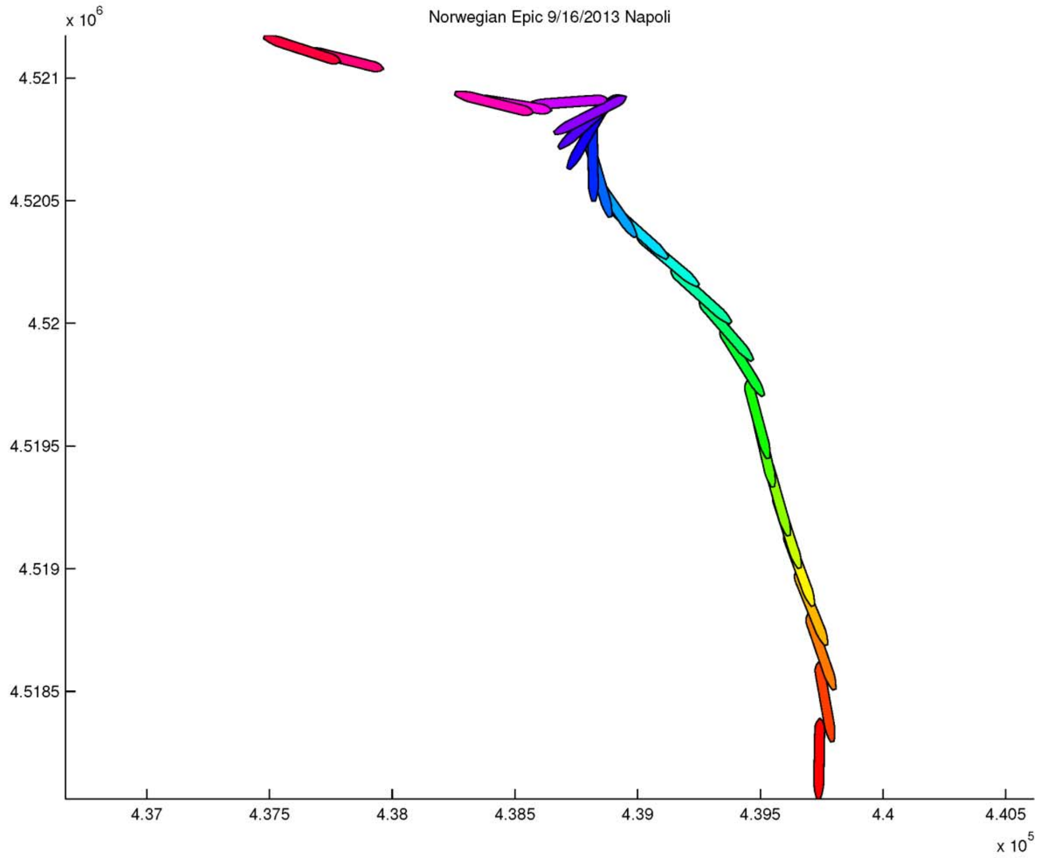
Main Engine(s)			
Type of Main Engine	Electric engine	Number of propellers	2
Number of Main Engine(s)	2	Propeller rotation	Right/Left
Maximum power per shaft	2 x 17600 kW	Propeller type	Azipod FP
Astern power	60 % ahead	Min. RPM	10
Time limit astern	N/A	Emergency FAH to FAS	70.8 seconds

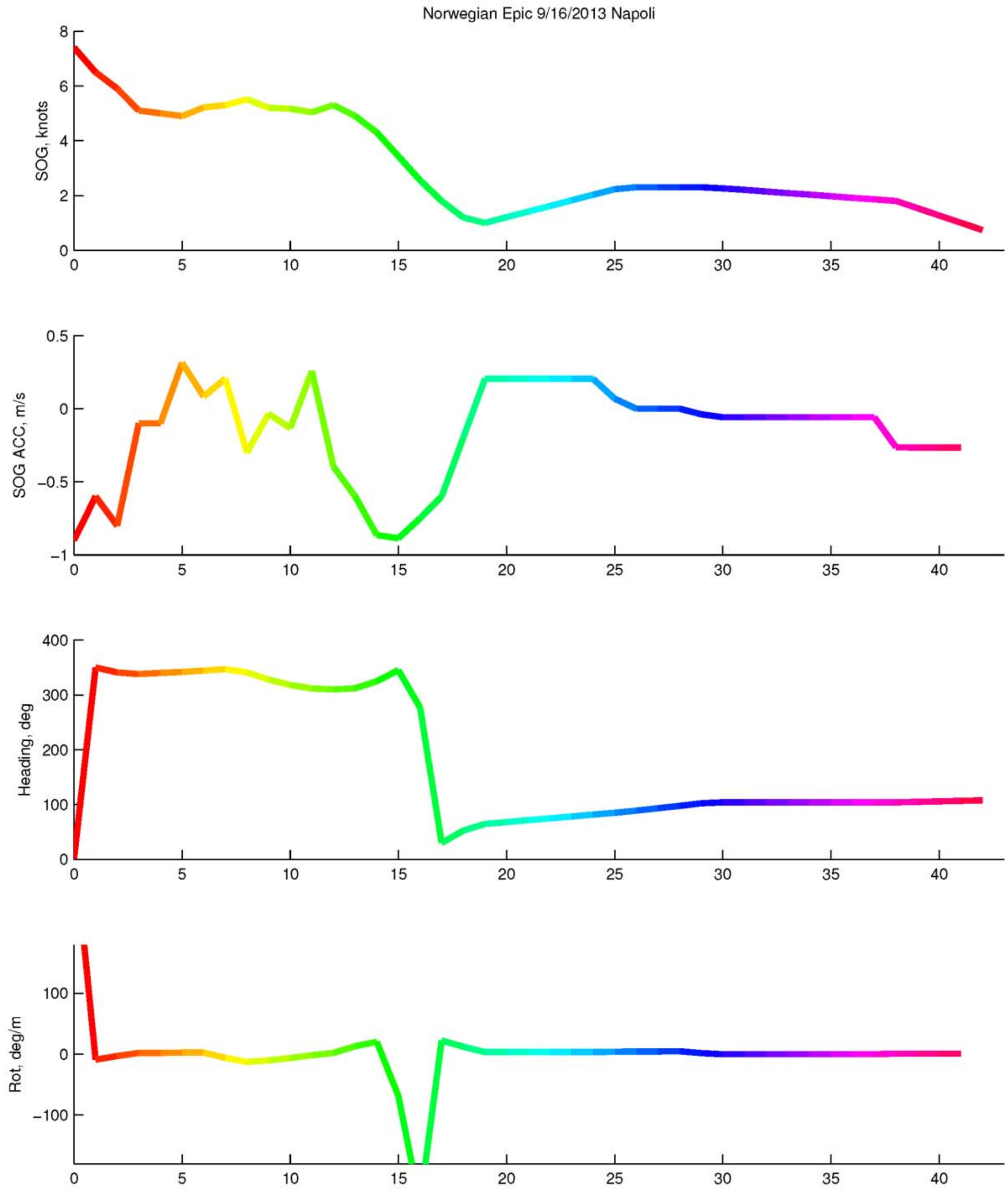
Engine Telegraph Table				
Engine order	Speed, knots	Engine power, kW	RPM	Pitch ratio
"100%"	24	34162	140	1.2
"80%"	20.7	21395	120	1.2
"60%"	14.9	9195	89	1.2
"40%"	9.7	2816	59	1.2
"20%"	3.7	412	28	1.2
"-20%"	-2.9	350	-28	1.2
"-40%"	-6.1	2880	-59	1.2
"-60%"	-9.2	9630	-89	1.2
"-80%"	-12	21114	-116	1.2
"-100%"	-12	21114	-116	1.2

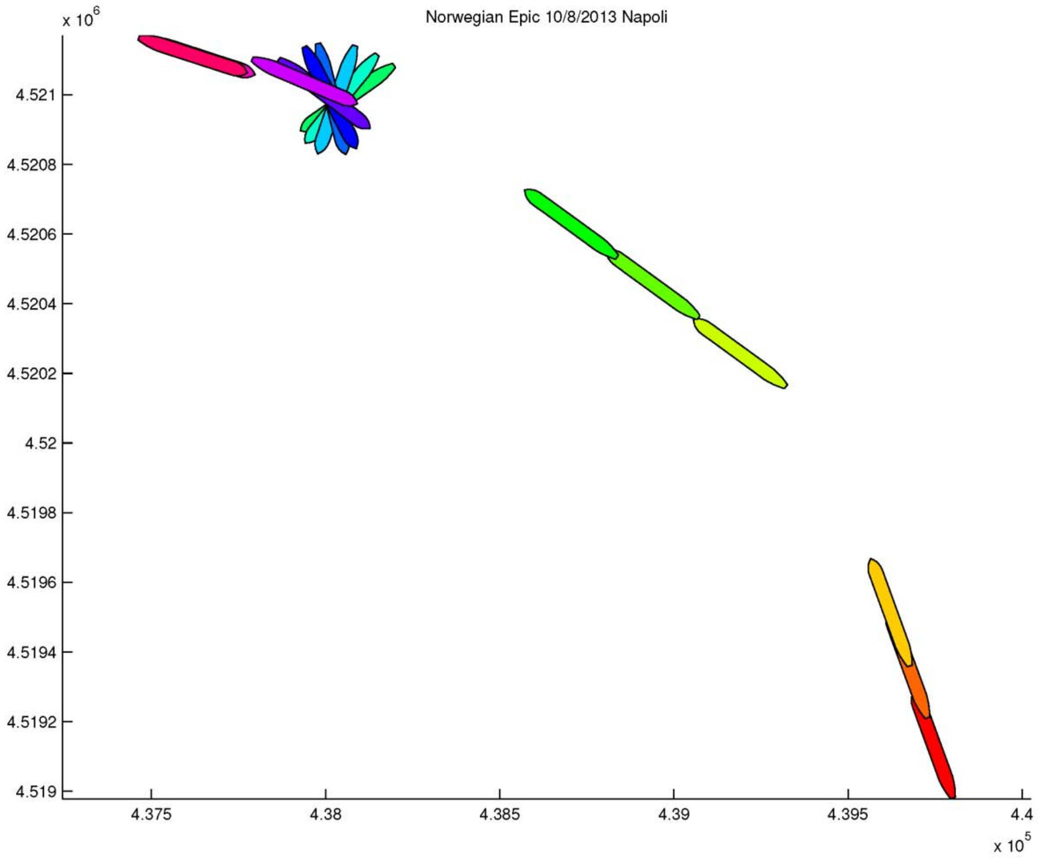
Figure A-2: Pilot Card for the Azipod Cruise Ship

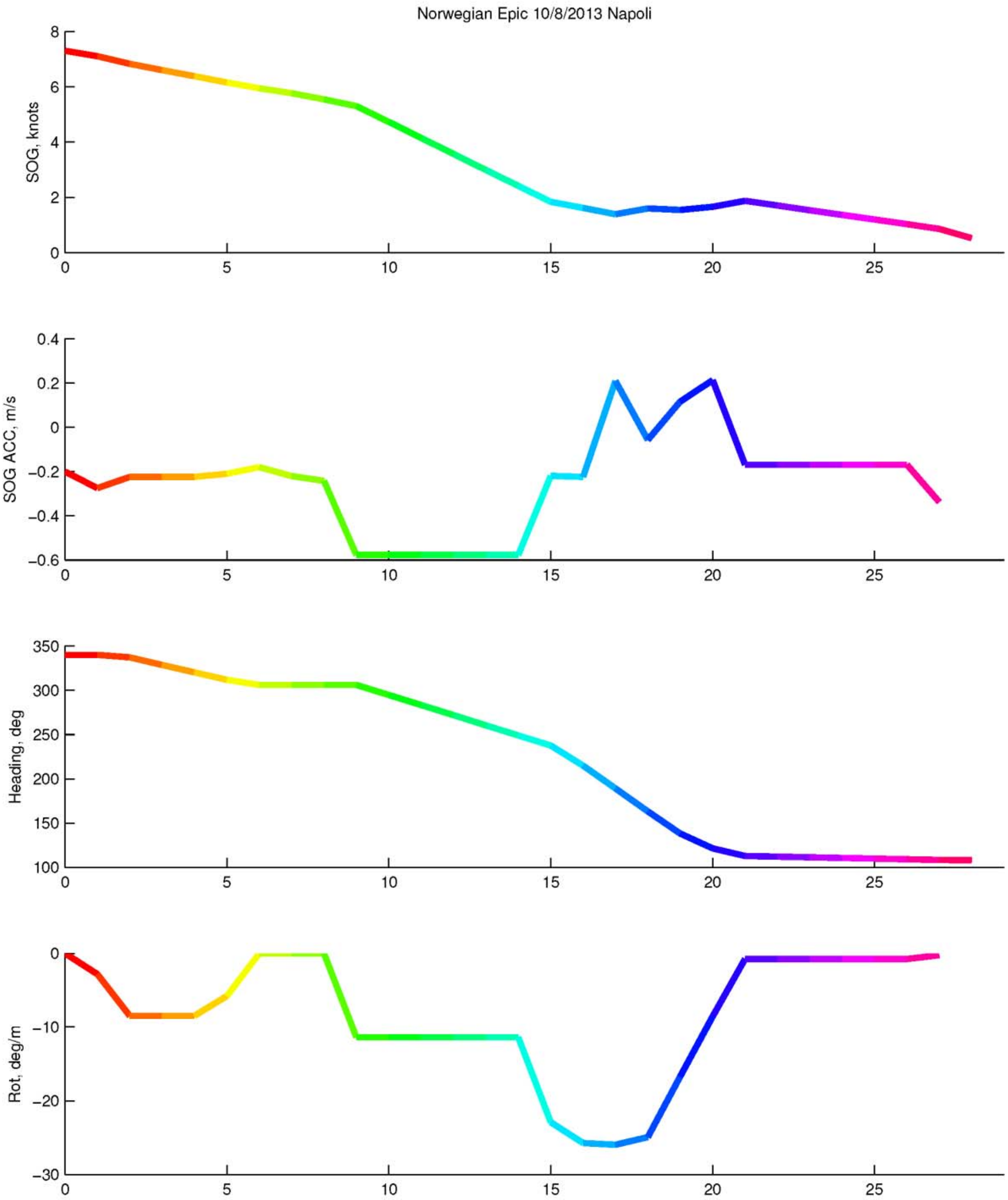
APPENDIX B

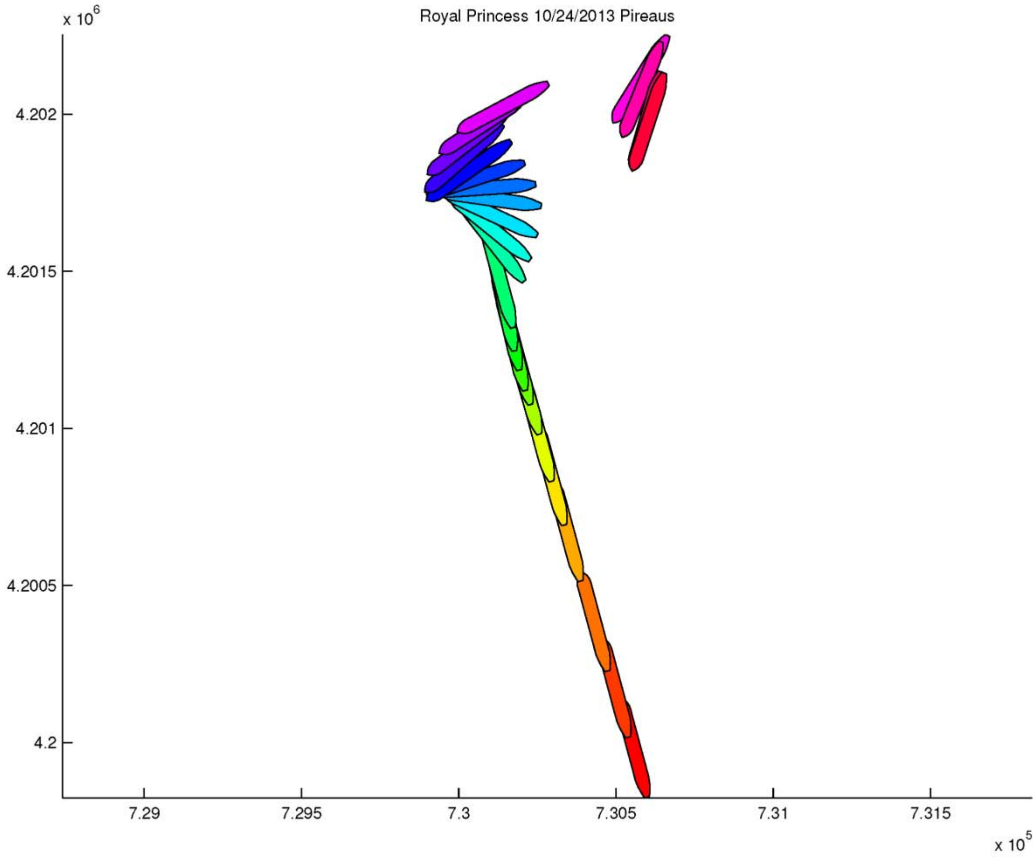
EXAMPLE FIXED PROPELLER CRUISE SHIP MANOUEVRES

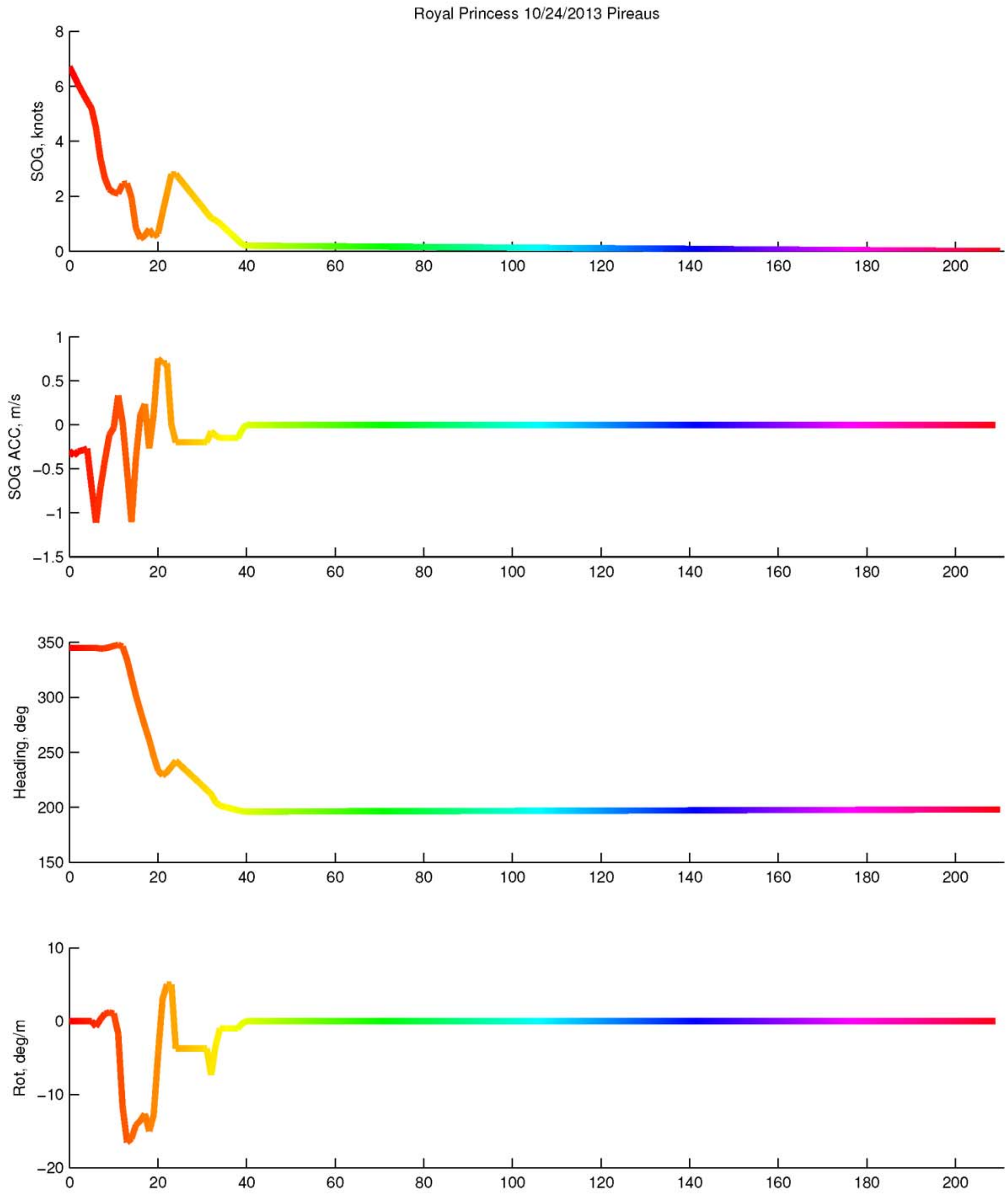

Norwegian Epic 9/16/2013 Napoli
x 10^6
4.521
4.5205
4.52
4.5195
4.519
4.5185
4.37
4.375
4.38
4.385
4.39
4.395
4.4
4.405
x 10^5

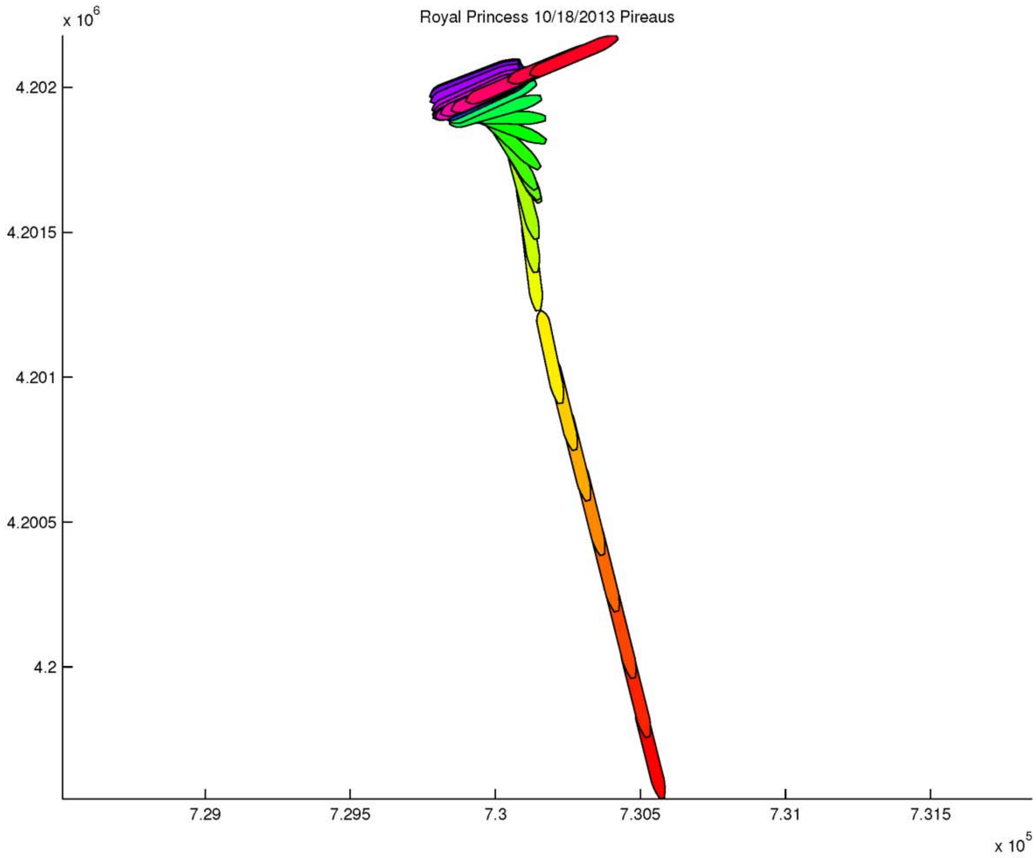

Norwegian Epic 9/16/2013 Napoli
SOG, knots
SOG ACC, m/s
Heading, deg
Rot, deg/m

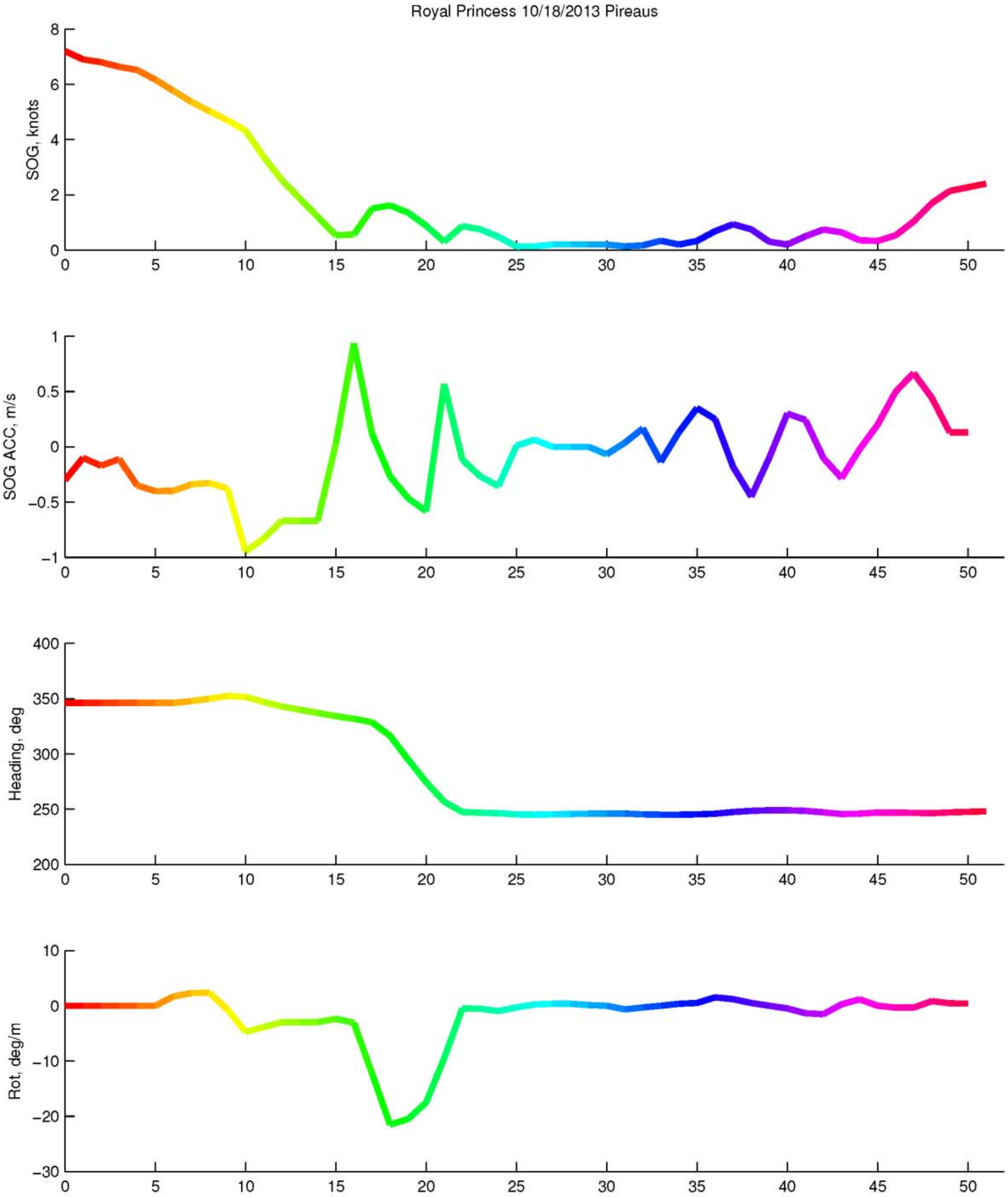

Norwegian Epic 10/8/2013 Napoli
x 10^6
4.521
4.5208
4.5206
4.5204
4.5202
4.52
4.5198
4.5196
4.5194
4.5192
4.519
4.375
4.38
4.385
4.39
4.395
4.4
x 10^5


Norwegian Epic 10/8/2013 Napoli
SOG, knots
SOG ACC, m/s
Heading, deg
Rot, deg/m
0
5
10
15
20
25


Royal Princess 10/24/2013 Pireaus
x 10^6
4.202
4.2015
4.201
4.2005
4.2
7.29
7.295
7.3
7.305
7.31
7.315
x 10^5


Royal Princess 10/24/2013 Pireaus
SOG, knots
SOG ACC, m/s
Heading, deg
Rot, deg/m
0
20
40
60
80
100
120
140
160
180
200


Royal Princess 10/18/2013 Pireaus
x 10^6
4.202
4.2015
4.201
4.2005
4.2
7.29
7.295
7.3
7.305
7.31
7.315
x 10^5


Royal Princess 10/18/2013 Pireaus
SOG, knots
SOG ACC, m/s
Heading, deg
Rot, deg/m
0
5
10
15
20
25
30
35
40
45
50