NAUTICAL AND RISK STUDIES FOR THE DELIMARA LNG TERMINAL IN MARSAXLOKK PORT, MALTA

Item 4: Real-time manoeuvring simulations

Final report

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Item 4: Real-time manoeuvring simulations

Final report

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1 INTRODUCTION

1.1 Project background

Enemalta is developing a new gas-fired power station near the existing Delimara Power Station on the north-eastern shore of Marsaxlokk Bay. The gas for the power plant will be imported through a new to build LNG terminal in Marsaxlokk Bay. Figure 1-1 shows the approximate position of the new terminal.

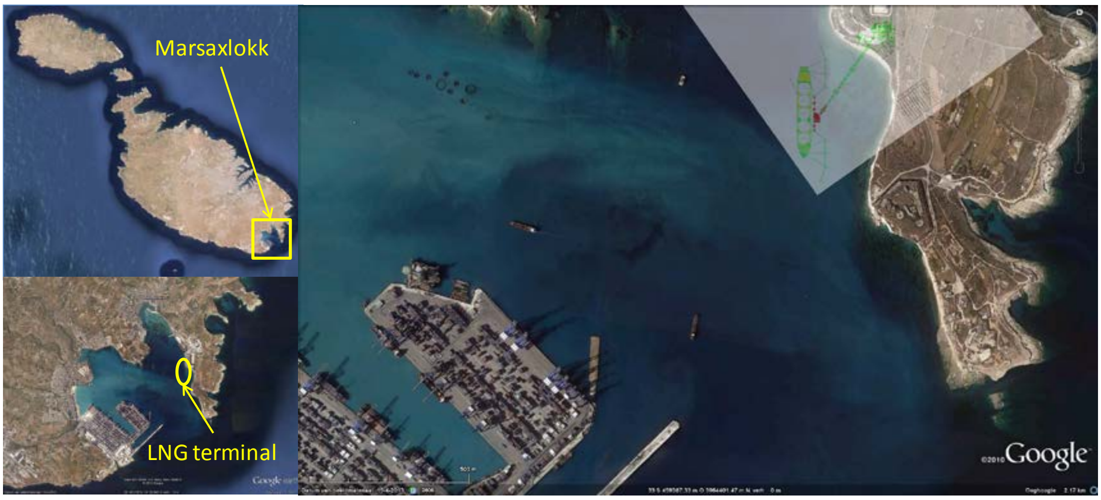


Figure 1-1 Marsaxlokk Port and approximate position of LNG terminal (source: Google Earth)

Enemalta has awarded the contract for design, construction and operation of the new power plant and LNG terminal to ElectroGas Malta. The LNG terminal proposed by ElectroGas consists of a jetty from the shore south of the power plant to a berth that is positioned where the bay is deeper, so that no dredging is required. A converted LNG carrier will be permanently moored at the jetty as Floating Storage Unit (FSU), delivering LNG through a cryogenic line over the jetty to the regasification unit onshore. The FSU berth has a conventional layout consisting of a platform, breasting dolphins and mooring dolphins (Figure 1-2). LNG will be imported by LNG carriers (further shortened to LNGCs) that will moor alongside the FSU.

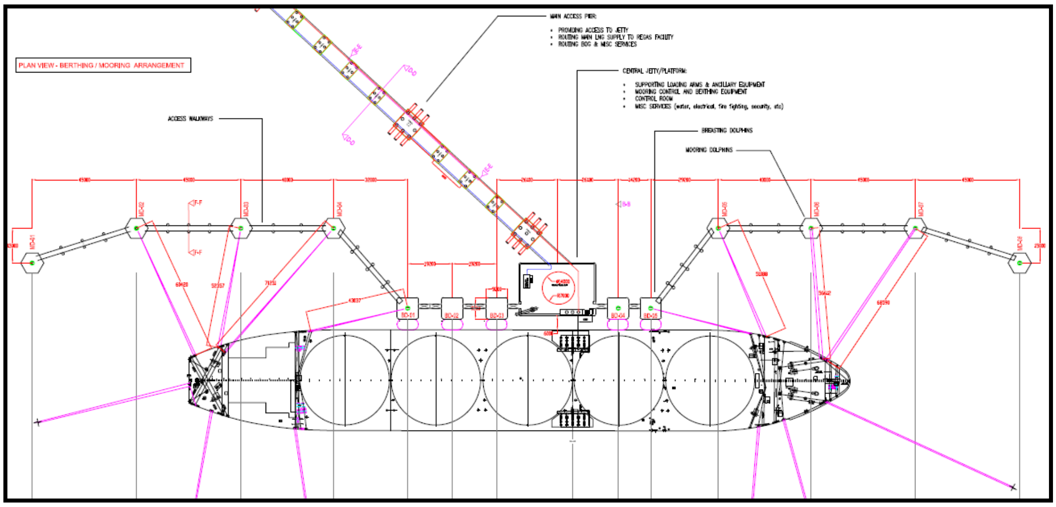


Figure 1-2 Proposed jetty configuration

To verify the design and evaluate safety aspects related to the permanent presence of the FSU in the port and to the regular call of LNGCs to the new LNG terminal, Enemalta has commissioned MARIN to carry out nautical and safety studies for the new LNG terminal. The study addresses a number of items raised by Transport Malta, the authority responsible for the port, who required:

1. Validation of proposed jetty/berth layout
2. Nautical and safety study
    a. Determine the required minimum navigation channel/fairway
    b. Determine the risk involved in the handling of an FSU and LNG carriers when navigating to the terminal
    c. Determine the nautical procedures for the handling of the FSU and LNGC during routine procedures and emergency situations
3. Site specific risk (safety) assessment including
    a. Cargo release
    b. Collision
    c. Fire and explosion
    d. Grounding

The contract for the study (Ref: DPS-GEN-1190) was signed on 25 August 2014 and is based on MARIN's proposal of 24 March 2014.

1.2 Objective, approach and scope of work

Objective

The objectives of the present nautical and risk study for the Delimara LNG terminal are:

- To evaluate the dimensions of the manoeuvring area and port approach
- To determine the operational envelope for ship manoeuvres (input for nautical procedures);
- To evaluate the proposed jetty layout and to determine the limiting operational conditions for safe offloading and for staying safely at the berth (input for nautical procedures);
- To determine the risk involved in the LNG operations in the port regarding grounding of LNGCs and collisions involving FSU or LNGC,
- To determine the consequences (cargo release, fire and explosion) of incidents involving the FSU or an LNGC.

Approach

The above mentioned items are evaluated in this dedicated nautical and safety study for the Delimara LNG terminal. The study consists of the following items:

1. Wave climate study to determine the normal and extreme wave climate outside Marsaxlokk port (frequency of occurrence of directions and wave heights)
2. Wave penetration calculations to determine the wave conditions at the terminal
3. Numerical moored ship response simulations to validate the jetty/berth layout and determine operational limits for the moored FSU;
4. Real-time manoeuvring simulations to verify dimensions of the fairway and determine operational limits for sailing with LNG carriers;
5. Nautical risk study to determine the risks of grounding and collisions involving the FSU or LNG carrier
6. Quantitative Risk Assessment to determine the consequences of collisions in terms of cargo release and risk of fire and explosion

The wave studies (items 1 and 2), which serve as input for the nautical studies (items 3 and 4) were carried out by ARCADIS. Items 3 and 5 were carried out by MARIN. Item 4 was carried out by MARIN in cooperation with MMP (Malta Maritime Pilots) and MMRTC (Malta Maritime Research and Training Centre). SGS Tecnos SA carried out the QRA in item 6.

1.3 Reports

The total study is presented in a series of reports, each one treating one of the above mentioned study items. Table 1-1 gives an overview of the reports presenting the results of the study.

Table 1-1 Overview of reports

Volume	Title	Main author
27689-1-MSCN	Item 1: Wave climate study	ARCADIS
27689-2-MSCN	Item 2: Wave penetration study	ARCADIS
27689-3-MSCN	Item 3: Moored ship response study	MARIN
27689-4-MSCN	**Item 4: Real-time manoeuvring simulations**	**MARIN**
27689-5-MSCN	Item 5: Nautical risk study	MARIN
27689-6-MSCN	Item 6: Nautical Quantitative Risk Assessment	SGS Tecnos

To support the design of the modifications to the FSU and the storm mooring for the FSU, some additional analysis was carried out for ElectroGas Malta on the data from the wave climate and wave penetration studies. This has been reported directly to EGM.

1.4 This report

This report (marked in bold in Table 1-1) describes the approach and the results of the real-time manoeuvring simulations. The following chapters describe:

- The set-up of the database
- The execution of the simulations
- The presentation, analysis and discussion of the results
- Conclusions and recommendations

This is the final report. Only a few minor textual changes were made compared to the previous revision.

Notations
In principle all parameters and variables have units according to the international SI conventions. Mariners with operational experience are, however, used to express distance, speed and force using different non-SI units such as nautical mile, knot and tonnes. As this report is meant to be read by people with a maritime background, the above units are often used in the description and discussion of results. Appendix A gives a more complete description of conventions and definitions used in this report.

2 SET-UP OF THE DATABASE

2.1 Introduction

The simulator database contains all data required for the simulations and includes the following items:

- Geometry and visuals
- Environment
- Ship models
- Scenarios

The database for the present study was based on the database of Marsaxlokk port as available on the MMRTC simulator. A copy was made of this database in which the new LNG terminal was implemented. After making the necessary preparations at MARIN's office, the database was uploaded to the MMRTC simulator, where the starting scenarios were finalised with the input from the Malta Maritime Pilots. The following sections describe the items included in the database.

2.2 Geometry and visuals

2.2.1 Layout

Enemalta and ElectroGas/URS provided various drawings of the new LNG terminal which were used to implement the terminal in the database. These drawings included:

- the overall layout of the terminal (Figure 1-2)
- the jetty (GDP1-OAS-MA-MP-DWG-DES-075-R4 (general layout - jetty).pdf)
- the position of the terminal in the bay (ENEM-URS-E2-00-DR-CT-00003.dwg)

Figure 2-1 shows the position of the LNG terminal with a part of the bathymetry and the geometry.

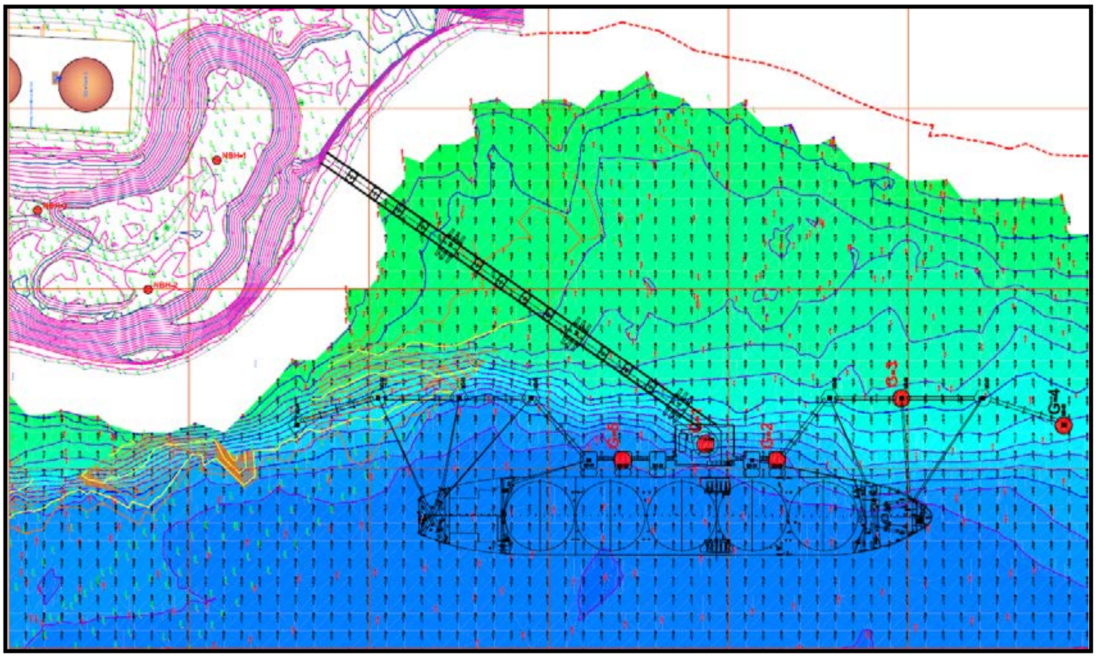


Figure 2-1 LNG terminal layout

The latest bathymetry data was provided in the following files:

- Bathymetric data from surveys between 2002 and 2013 by Transport Malta (Bathymetric Survey TM - 2013.dwg)
- Data from a survey of the site by Randolph Camilleri Surveys Limited (1839DEL7_02 MSL - bathymetric survey.dwg)

The depth outside the surveyed areas was taken from nautical charts of the area.

2.2.2 Visuals

The visuals of the database were adapted to include the LNG terminal. The platform, breasting dolphins, mooring dolphins and connection to shore were included based on the provided drawings. Further some smaller modifications to the shoreline were made such as removal of the area indicated on the nautical chart as “being reclaimed” as this is not shown on the provided drawings.

2.2.3 Navigational aids

No changes were made to the navigational aids for the simulations.

2.3 Environmental conditions

The database includes information regarding the water level and current, the wind and the waves. The conditions implemented in the database are briefly described in the next sections.

2.3.1 Current and water level

The existing database of the port of Marsaxlokk includes a uniform current field of 1 m/s to the south. The pilots use this current field in a dynamic way. At the start of the run the required magnitude and direction of the current is created in the run using a factor for the current speed and an offset to the direction. If during the run the current experienced by the sailing ship changes (e.g. because it is reaching the port), this approach is again used to modify the current.

In the simulations this approach was used during the first days. Based on discussions with the pilots a simple spatially varying current field was prepared with a 1 kn SW-going current seaward from the S cardinal buoy near the Delimara peninsula and a 0 current inside the port. In between these two areas the simulator will interpolate linearly. This spatially varying current field was used on the fourth day of the simulations.

It may be that the current in the port entrance is more complex due to the geometry of the area. It may be worthwhile to investigate the possibility of further enhancing the database by implementing spatially varying current fields from e.g. numerical calculations of the flow in the port approaches. Note that the simulations carried out by Svasek for the EIA [5] were aiming at identifying possible areas of stagnant water due to the LNG terminal and plots show only the port area. In those calculations only wind forcing was therefore considered, no forcing from tidal currents.

As the tidal variations in the port are small, all simulations were carried out for the same water level of CD + 0.4 m. This is a relatively low water level (approx LWS) which is in principle conservative from manoeuvring point of view (larger turning circles at smaller underkeel clearance). The depth near the berth and in the approaches is around 17 m or more, which is fairly deep considering the draught of the LNGC, so that the results from the simulations are not very sensitive to the water level.

2.3.2 Wind

Based on experience in previous projects, the limiting wind speed for manoeuvres involving LNG carriers is usually in the order of 10 – 14 m/s. The wind climate as determined in the wave climate study can be used as reference for the frequencies of occurrence or exceedance for these wind speeds. For wind from westerly directions this is likely to be on the conservative side as the wind speed in the port is expected to be lower for these directions than on open sea due to the presence of the island (different surface roughness and hence a different wind profile near the surface. For easterly winds the Delimara peninsula may provide some shielding, but considering the height (about 20-25 m above sea level) and the distance from the jetty to the shore (about 250 m) this effect may not be very strong. Assuming no shielding effects exists is considered to be a conservative and prudent approach.

For the frequency of occurrence of the wind at the site, the offshore wind climate based on the 33 year data from Oceanweather is used as reference. Figure 2-2 shows the wind rose and the probability of exceedance of the wind speed for this station. It can be seen that a wind speed of 12 m/s is exceeded about 7% of time; a wind speed of 14 m/s about 2.7% of time. NW is the dominant direction with the 300°N sector being most frequent, but SE wind occurs regularly as well.

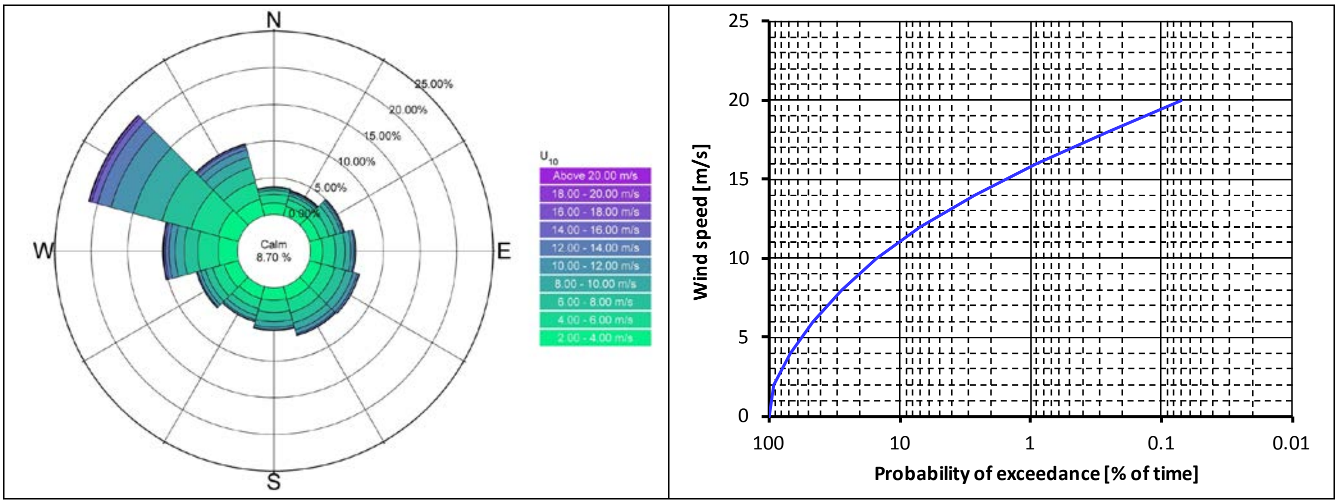


Figure 2-2 Wave rose (left) and frequency of exceedance of the wind speed (right)

The conditions for the manoeuvring simulations were selected in discussion with the Malta Maritime Pilots (MMP). Based on their experience in the port, they expect that wind from west (beam on when near the terminal) and from southeast and south (largest wave penetration) will be the most critical. Uniform wind fields for the 150°N, 180°N and 270°N were implemented in the database. However, local differences in wind speed and direction occur due to sheltering by the FSU and vessels moored at other berths (e.g. container terminal). This effect was included in the database. Sheltering of other objects was not included. Note that uniform wind fields can be easily changed from the instructor station at the start of a simulator run or during a run. In one of the runs of the simulations with wind direction was changed from 270°N to 300°N.

Gusting of the wind is included in the simulations. The wind speed varies in time based on a Davenport spectrum for the wind speed based on the upwind foreland roughness.

2.3.3 Waves

Arcadis provided wave fields for the relevant directions covering Marsaxlokk port and the approach. Wave fields were provided for wind speeds of 10, 12 and 14 m/s for directions 150 to 330°N. These were from dedicated SWAN calculations for these conditions. In the post-processing of the results, ARCADIS had separated the incident and reflected waves.

The conditions for the manoeuvring simulations were selected in discussion with the Malta Maritime Pilots (MMP). Based on their experience in the port, they expect that wind from west (beam on when near the terminal) and from southeast and south (largest wave penetration) will be the most critical. Wave fields corresponding to wind from the directions 150, 180 and 270°N were therefore implemented in the database.

For 150 and 180°N the incident wave field for 14 m/s was implemented as sea, the reflected wave field as swell waves. In this way the choppy conditions just outside the breakwater due to incident and reflected waves are well incorporated in the database. These wave fields are shown in Figure 2-3.

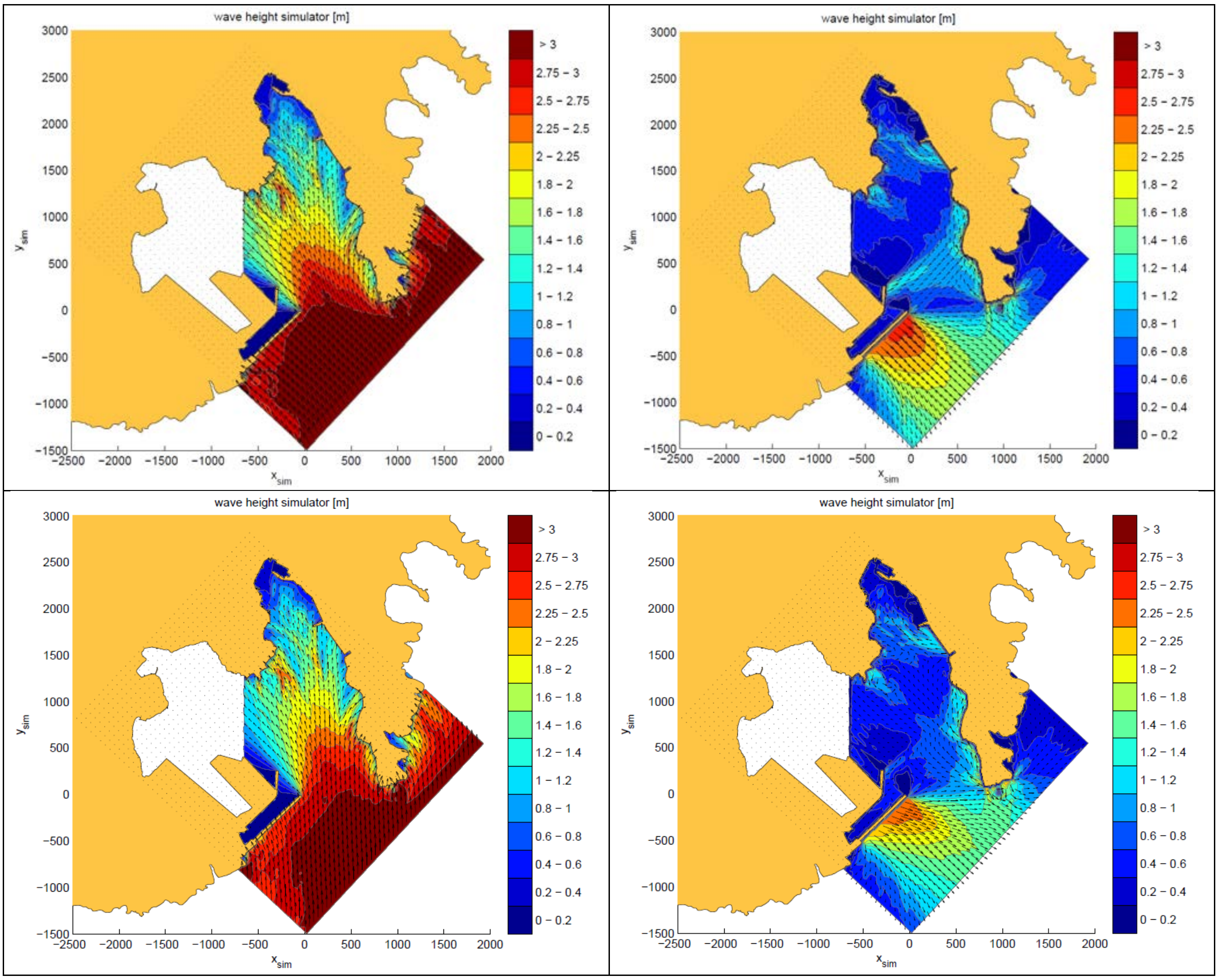


Figure 2-3 Incident (left) and reflected (right) wave field for 150°N (top) and 180°N (bottom) as implemented in the simulator database

For wind from 270°N the wave field inside the port is a combination of waves coming around the island and penetrating into Marsaxlokk port and waves locally generated in the bay. The SWAN wave calculations for 270°N showed that in part of the manoeuvring area near the terminal the mean wave direction was from SW, because the westerly locally generated waves and the waves penetrating into the port with a southerly direction are similar in height. As this SW direction is not realistic, the provided wave fields were manipulated in the processing to obtain a more realistic description of the waves in the simulations. The locally generated waves were taken from the incident wave field calculated for 270°N for all points west (and north) of the breakwater head. For other points in the domain north of the breakwater head a uniform wave height of Hs = 0.5 m was assumed. This wave field was implemented as "sea" in the database (see Figure 2-4, left panel). Due to the geometry of the coast, the direction of the waves outside the port for wind from 270°N is similar to the wave direction for wind from 240°N. The wave field for 240°N was therefore used for the wave height pattern for the waves penetrating into the port and in the port approach. The wave height was reduced using a scaling factor (0.666) estimated from a comparison of the calculated wave heights in the port entrance for 270°N and 240°N. This estimated wave field for the wave penetration from open sea was implemented as "swell" in the database (see Figure 2-4, right panel).

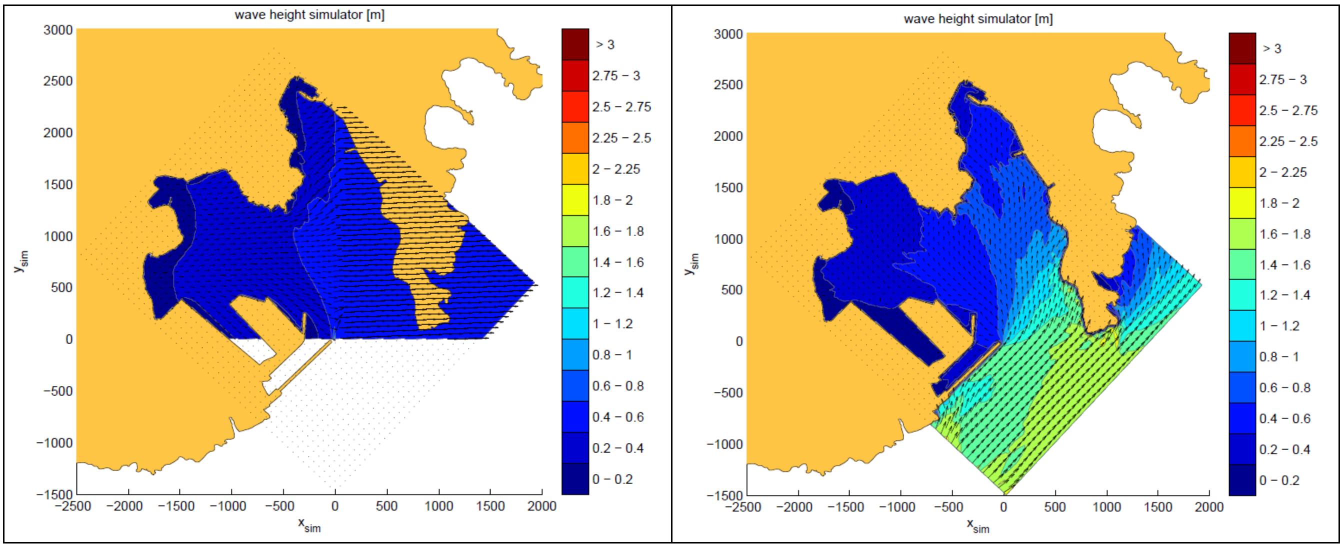


Figure 2-4 Locally generated waves (left) and waves penetrating from open sea (right) for wind from 270°N as implemented in the simulator database

2.4 Ships

The simulation database includes models for the ships that are actively steered during the simulations, referred to as "ownships", models for the supervisor-operated tugs and other vessels moored or sailing along a prescribed track that can be controlled by the simulator supervisor if required. The latter are referred to as "targets". The following sections describe the ownships and the tugs used in the simulations.

2.4.1 FSU

The Wakaba Maru, an LNGC of 283x44.8m will be used as FSU for the new terminal. To serve as FSU the Wakaba Maru will be modified to include e.g. quick release hooks (QRHs) to moor the LNGCs delivering LNG alongside. Details of the changes that will be made were not yet available when preparing the database for the simulations. Data received regarding the Wakaba Maru included:

- General arrangement drawing (see Figure 2-6)
- LNG Form B (file Wakaba Maru - LNG FORM B 2014.04.24.pdf)

Some additional data was found in the SIGTTO publication [2]. Figure 2-5 shows a picture of The Wakaba Maru.

To allow the FSU to move on its mooring, the FSU was implemented as a tertiary ship connected to the jetty with mooring lines. A mathematical model of the Wakaba Maru was prepared based on an existing model with similar hull dimensions. When preparing the database it was not yet decided whether the propulsion system of the Wakaba Maru would be maintained while serving as an FSU or that this would be disabled. The properties of the propulsion were therefore also modelled according to the provided data of the Wakaba Maru. The validity of the model ranges from a depth over draught ratio (h/T) from 1.2 to 2. The latter can be regarded as deep water. For the wind coefficients the latest values from SIGTTO for a Moss-type LNGC were used [4]. The particulars of the vessel as implemented in the simulator model are shown in Table 2-2.

Figure 2-5 Picture of Wakaba Maru (source: MarineTraffic.com)

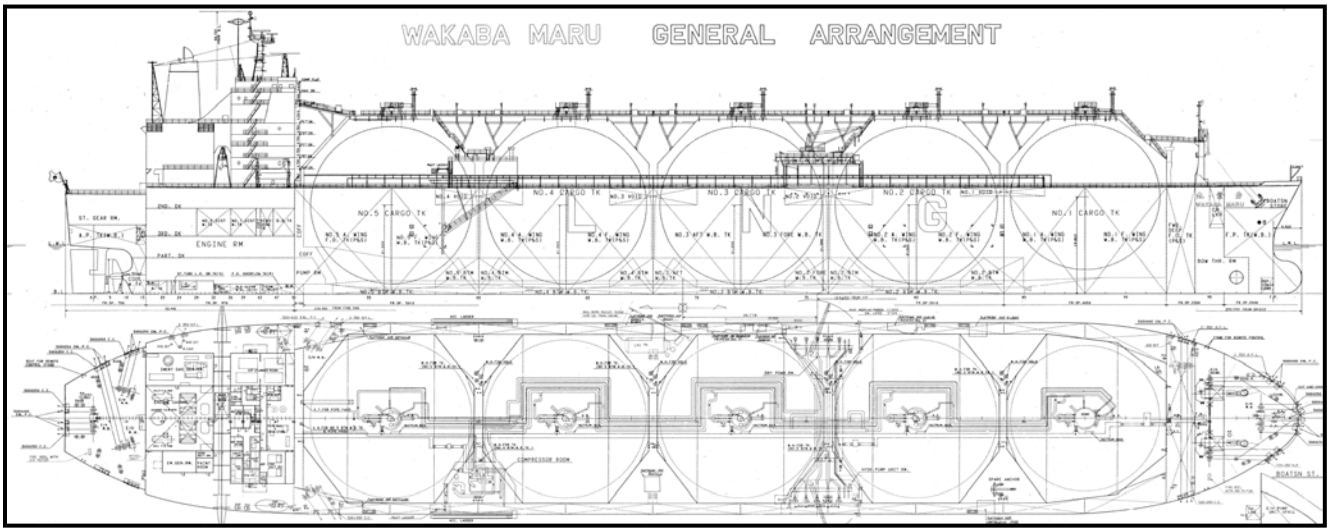


Figure 2-6 General arrangement of the Wakaba Maru

2.4.2 LNGC

Various LNGCs may be calling at the terminal. Socar Trading, who may be providing the LNG for the power plant, provided details (“FormB”) of a few typical vessels that might be used for that purpose. Table 2-1 summarizes the main particulars of these vessels. Note that some values for the Hispania Spirit seem to be erroneous. The extreme draught looks very low, while the wind areas are not in the expected order of magnitude either.

Table 2-1 Main particulars of LNGCs that may be used for LNG delivery to the FSU

Dimension	Unit	GEMMATA	Castillo de Santisteban	TRINITY ARROW	Hispania Spirit
		294x46m	300x46m	289.9x44.7m	279.8x43.4m
		Moss-Rosenberg	membrane	membrane	membrane
Length over all	m	294.00	299.9	289.93	279.8
Length between perps	m	276.00	288	276.00	268.8
Beam	m	46.00	45.8	44.70	43.426
Depth	m	25.50	26.015	26.00	26
Draught (loaded)	m	11.05	11.8	11.396	11.4
Displacement	tons			105,000	
Capacity (98.5%)	m^3	135,342	170,410	152,655	138,517
Dead weight tonnage	tons	68,200	118,990	79,556	67,937
Engine-type		Steam turbine	Diesel-electric	Steam turbine	Steam turbine
Power (service)	kW	21,320	27,000	26,480	23,832
Number of revolutions	rpm	81	89.1	78.2	85
Service speed	kn	18.5	19.5	19.5	19.5
Frontal wind area	m^2	1369	1330	1120	2038
Lateral wind area	m^2	6782	6300	6004	672

SOCAR indicated that the Gemmata was a likely vessel to be used for delivery of LNG to the new power plant. As the wind areas of Moss-type LNGCs is generally larger than the wind areas of membrane LNGCs of similar dimensions, the wind load will be larger. This means that this vessel is expected to require larger tug forces to control it when berthing it alongside the FSU. As the power of the engine seemed also low compared to the other data, this vessel was selected for the real-time manoeuvring simulations. SOCAR provided a pilot card with some additional information for regarding e.g. telegraph settings of the vessel. Based on the provided information an existing model of an LNGC of the same principal dimensions was adapted to match with the provided data for the Gemmata. A model was prepared for both the loaded and ballasted LNGC. The main data of the LNGC model used in the simulations are summarized in Table 2-2.

Table 2-2 Main particulars of the ships included in the simulations

Dimension	Unit	FSU Wakaba Maru 283x44.8m	LNGC Gemmata 294x46.0m	
		loaded	loaded	ballast
Length over all	m	283.0	294.0	
Length between perpendiculars	m	270.0	276.0	
Beam	m	44.8	46.00	
Depth	m	25.0	25.5	
Draught	m	11.5	11.4	9.6
Displacement	tons	99,890	101,600	85,510
Capacity (at 98.5% filling level)	m^3	123,780	135,342	
Dead weight tonnage (fully loaded)	tons	66,317	71,446	
Engine-type		Steam turbine	Steam turbine	
Power	kW		21,320	
Number of revolutions	rpm	95	81	
Service speed	kn	19.3	18.5	21.2
Number of propellers		1	1	
Diameter of propellers	m		8.6	
Pitch ratio	-		0.872	
Number of rudders		1	1	
Maximum rudder angle	degr	35	35	
Bow thrusters	kW	-	1,620	
Frontal wind area	m^2	1187	1317	1395
Lateral wind area	m^2	7180	6330	6809

The telegraph settings for the LNGC are shown in Table 2-3. These data were taken from the provided pilot card. The provided pilot card further mentioned a minimum propeller speed of 24 rpm (at a speed of 6 kn). To one of the participants this seemed a fairly high value as in his experience a steam turbine allows lower minimum rpm.

Table 2-3 Propeller speed (rpm) and ship speed as function of telegraph setting (loaded vessel)

Telegraph	LNGC Gemmata 294x46.0m	
	propeller [rpm]	speed [kn]
Sea full	81	18.5
Harbour full	46	11.4
Half	39	9.7
Slow	33	8.2
Dead slow	24	6.0

2.4.3 Tugs

Tugs in Marsaxlokk

During the manoeuvres the LNGC will be assisted by tugs. The present fleet of Tug Malta was used as reference for the tugs used in the simulations. Tug Malta operates a fleet including several modern, powerful tugs in Marsaxlokk and Valetta. As these tugs are also used for handling large container vessels in Marsaxlokk, they are considered suitable and sufficient for the operations with LNGCs as well. The strongest tugs of Tug Malta were considered in the simulations. These are shown in Table 2-4. The last column indicates the way the tug was implemented in the database. Recently Tug Malta welcomed the MT Malta, a Damen 2411 with a bollard pull of 71 t as newest tug in their fleet (September 2014; http://www.tugmalta.com/news/detail/News26). This is similar to the Pawlina and Wenzina.

Table 2-4 Tugs considered in the manoeuvring simulations

Name	Built [year]	Dimensions		Type	Bollard pull ahead / astern [t]	Simulations
		Loa [m]	B [m]			
MT Spinola	2009	36.65	13.60	VS AVT 37/70 (design Robert Allen)	81 / 81	C-tug VS_80
MT Pawlina	2006	30.60	11.20	ASD Damen 3111	67.1 / 62.2	C-tug ZP_70
MT Wenzina	2006	24.55	11.49	ASD Damen 2411	68.1 / 64.3	C-tug ZP_70
MT St Elmo	2011	30.25	11.75	ASD Ramparts 3000 (design Robert Allen)	75.0 / 71.0	C-tug ZP_70
Damen3213	na	32.14	13.29	ASD Damen 3213	76.5 / 70.4	Free-sailing

Tug requirement

To verify whether the capacity of these tugs is sufficient, a short static analysis of the wind loads on the LNGC and the required forces to compensate this has been carried out. In the final stage of the manoeuvre when the LNGC is berthing alongside the FSU, the wind load must be entirely compensated by the tugs.

The wind loads on the vessel are shown in Figure 2-7 as function of the wind direction relative to the ship for a wind speed of 14 m/s. The longitudinal force F_x is shown in orange, the lateral force F_y in red and the yaw moment F_n (here scaled with Lpp to have values of similar order) in purple.

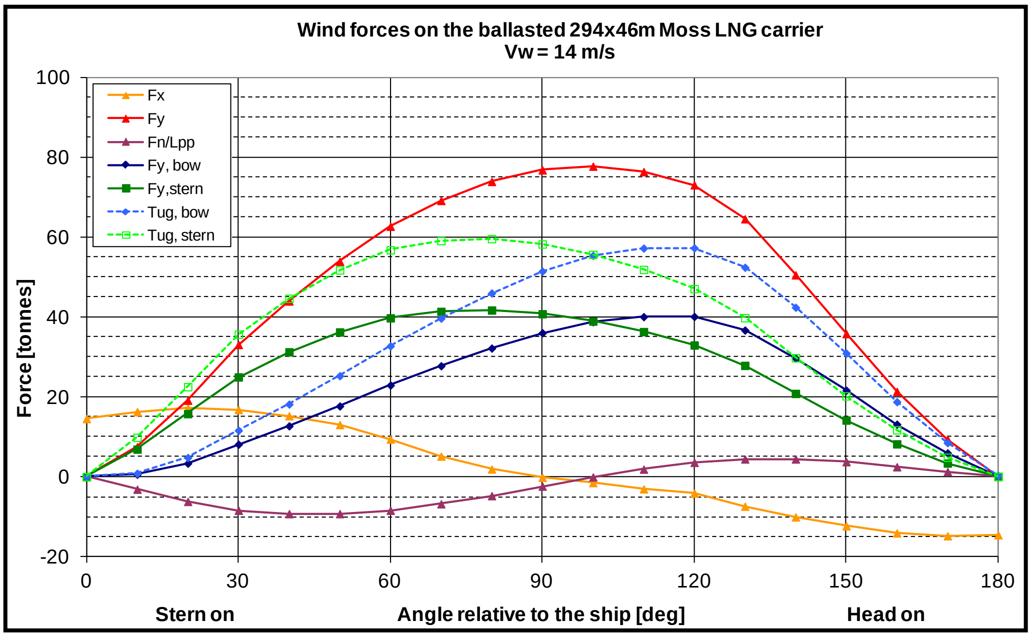


Figure 2-7 Wind forces and required lateral force to control the ballasted LNGC in 14 m/s wind as function of the wind direction relative to the ship

It can be seen that the lateral force F_y is largest when the wind is nearly beam on (100 degrees); the maximum force is 78 tonnes. To keep the ship under control, the lateral force and yaw moment must be compensated with the tugs. The force required at bow and stern is shown by the drawn blue and green line. For a relative direction of 100 degrees, the yaw moment is negligible and the force required at bow and stern are both about 39 tonnes. If the wind is a more bow or stern on the maximum forces are slightly higher.

To allow for sufficient margin (reserve capacity) for factors such as wind gusting, stopping or starting lateral motions of the ship, etc it is assumed that only 70% of the tug capacity should be used to compensate the wind. The total capacity of thruster(s) and tug(s) at both bow and stern is hence found by dividing the required force by 0.7. The required tug capacity (assuming no thrusters) is indicated by the dashed blue and green line in Figure 2-7. It can be seen that for a wind speed of 14 m/s this must be about 60 tonnes. Four tugs of about 70 tonnes are therefore expected to be sufficient to carry out the manoeuvres safely. As the total capacity of the 4 tugs is about twice the required capacity, this seems to provide some redundancy in case of a tug failure. Note also that not all tugs are used at the same moment to counteract the wind force. The stern tug may also be involved in pulling the LNGC astern to the berth.

Tugs in the simulations
The four tugs of Tug Malta were included in the database as instructor-operated tugs (C-tugs, see last column of Table 2-4). These C-tugs are operated at the instructor station by setting the required direction and force of the tug. Further the mode of operation can be set (push/pull or work on a line), while automated procedures are available for approaching and leaving the assisted vessel. The actual force that the C-tug delivers is determined from capability diagrams that take into account factors such as the speed of the assisted vessel, the position where the tug is connected to the ship, the operating mode (push/pull or on a line), the pulling or pushing direction, etc. These diagrams are different for different types of tugs (conventional, ASD-type tugs, Voith-Schneider type tugs). The tugs can be seen in the visuals, but the effect of motions of the tugs in waves and line dynamics on the towing forces are not included (no snap loads). The behaviour of the C-tugs for e.g. delays when repositioning is realistically modelled using automated procedures.

The instructor will generally apply realistic delays for e.g. connecting or disconnecting the tow line. In the simulator runs, the instructor will generally use an effective bollard pull of about 90% of the maximum bollard pull as limit. This reduction is to incorporate the following effects that often occur in practice:

- The output of the engine is less due to a different setting of the load control; this is done to protect the engine. Under special circumstances the engineers on board of the vessel can change this setting, but normally they will not be willing to do so;
- The efficiency of the propellers is less due to aging of the propellers, the surface is less smooth and often the pitch has changed locally due to small damages to the blades;
- Crew is reluctant to apply full power as this often results in a lot of noise and strong vibrations. When it is applied it will only be done for a relatively short period.

The assumed reduction is 10% for the ASD tugs.

In addition to these instructor-operated tugs, one tug with similar capacity was included as a free-sailing tug. This tug was a Damen 3213 for which a model was already available in the MMRTC database. This tug was operated from MMRTC's FMB2 by tug masters from Tug Malta.

2.4.4 Targets

Several moored vessels were included as "targets" in the database. These are to add more realism to the simulations with respect to the visuals and the manoeuvring space.

For the present study the following vessels were moored on the database:

- LPG tanker of 103x14m on Oil Tanking jetty 3
- Product tanker of 173x32m on Oil Tanking jetty 2
- Product tanker of 173x32m on Oil Tanking jetty 4
- Container vessel of 382x57m on Freeport Terminal 2 North
- Coaster of 125x21m on Freeport Terminal 2 West
- Container vessel of 225x32.2m on Freeport Terminal 2 South, west side
- Container vessel of 118x18.5m on Freeport Terminal 2 South, east side
- Container vessel of 343x42.8m on Freeport Terminal 1, middle
- Container vessel of 225x32.2m on Freeport Terminal 1, west side
- Product tanker of 173x32m on San Lucian terminal
- Product tanker of 173x32m on MX Dolphins (Has Saptan Fuelling Dolphin)

The container vessel on Terminal 2 North and the product tanker on MX Dolphins are most relevant for the available manoeuvring space. Note that in future the port regulations may require that an LNGC cannot moor at the new LNG terminal if a tanker is using MX Dolphins and vice versa. The situation considered in the present simulations is therefore a worst case in terms of available space for manoeuvring.

2.5 Prepared scenarios

Scenarios define the starting conditions for the runs. They describe the area (geometry, depth, radar, visuals), the wind, wave and current fields to be used, the starting position and initial speed of the vessel(s) in this area, propeller speed, connected lines, etc. Scenarios were prepared for the following manoeuvres:

- Arrivals of the loaded LNGC to the terminal (starting in the approaches)
- Departures with the ballasted LNGC alongside the FSU

Each of the scenarios was prepared for different combinations of current, wind, and waves. The starting position of the LNGC in the approach to the port was initially about 2 km from the breakwater. As this appeared to be too short to adapt the heading and speed of the vessel to the conditions and connect the tugs, this starting position was moved about 700 m further out. Table 2-5 gives an overview of the prepared scenarios. Note that at the start of a run the conditions can be adapted by applying a scaling factor for the magnitude and an offset of the direction of wind, waves and current.

Table 2-5 Overview of prepared scenarios

sailing ship	manoeuvre	vessel at start			wind		sea waves			swell waves			wave fields
		position	speed [kn]	heading [°N]	speed [m/s]	direc [°N fr]	Hs [m]	Tp [s]	direc [°N fr]	Hs [m]	Tp [s]	direc [°N fr]	
loaded lngcarrier 294x46x11.4	arrival	approach	6	316	14	150	3.25	8.5	150	1.55	8.5	306	sea: marsaxlokk_sea_150_inc.as swell: marsaxlokk_sea_150_refl.as
loaded lngcarrier 294x46x11.4	arrival	approach	6	316	14	180	3.2	8.5	180	1.5	8.5	300	sea: marsaxlokk_sea_180_inc.as swell: marsaxlokk_sea_180_refl.as
loaded lngcarrier 294x46x11.4	arrival	approach	6	316	14	270	0.5	2.0	270	1.7	8.0	220	sea: marsaxlokk_sea_270_inc_local.as swell:marsaxlokk_sea_240_tot_f0_666.as
ballast lngcarrier 294x46x9.5	departure	alongside	0	180	14	150	3.25	8.5	150	1.55	8.5	306	sea: marsaxlokk_sea_150_inc.as swell: marsaxlokk_sea_150_refl.as
ballast lngcarrier 294x46x9.5	departure	alongside	0	180	14	180	3.2	8.5	180	1.5	8.5	300	sea: marsaxlokk_sea_180_inc.as swell: marsaxlokk_sea_180_refl.as
ballast lngcarrier 294x46x9.5	departure	alongside	0	180	14	270	0.5	2.0	270	1.7	8.0	220	sea: marsaxlokk_sea_270_inc_local.as swell:marsaxlokk_sea_240_tot_f0_666.as

Figure 2-8 shows typical starting situations for arrival and departure runs. Note that the light blue tug is the free-sailing tug operated from the second full mission bridge, the purple tugs are the instructor-operated tugs.

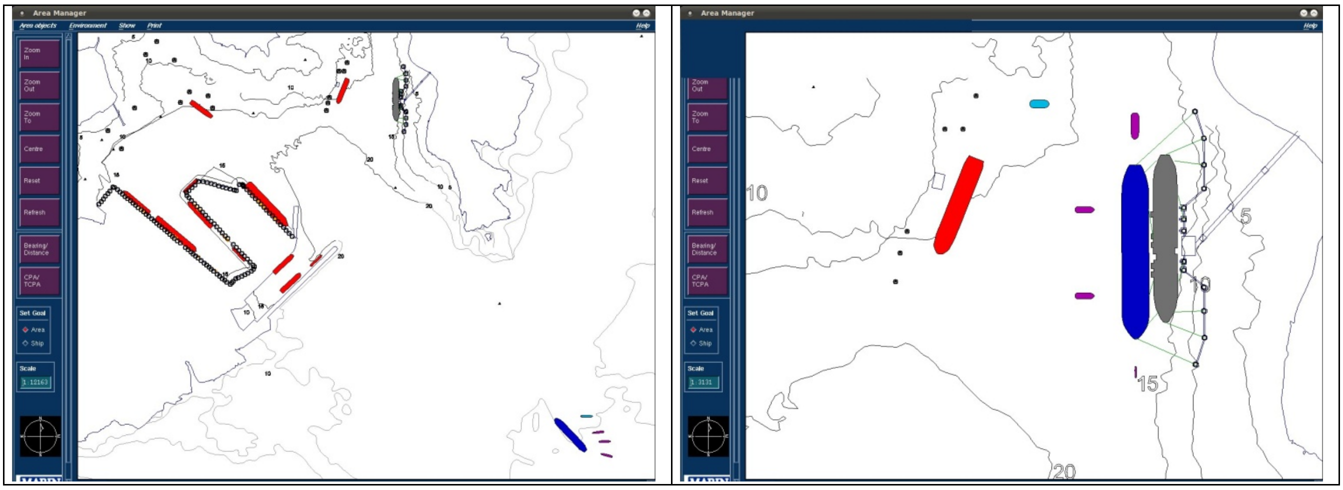


Figure 2-8 Typical start situation for arrival (left) and departure (right) scenario

3 SIMULATIONS

3.1 General

The real-time manoeuvring simulations were carried out from 24 to 28 November 2014 at MMRTC's simulator facilities in Marsa, Malta. A total of 21 pilots and tug masters participated in the simulations in relation to their availability according to their rosters. Joseph Brincat and Stephen Cauchi lead the simulations on behalf of MMRTC. Stephen Cauchi was operating the simulator from the instructor station in most of the runs. One of MARIN's instructors supervised the simulations together with MARIN's project manager. Participants in the simulations were:

- Jesmond Mifsud MMP pilot (24 November)
- Joseph Micallef MMP pilot (24 November)
- Anthony Chetcuti MMP pilot (24 November)
- Mark Muscat Tug Malta tug master (24 November)
- Paul Schembri Tug Malta tug master (24 November)
- Ian Pale Bardon MMP pilot (25 November)
- Marco Portelli MMP pilot (25 November)
- Noel Galea MMP pilot (25 November)
- Paul Camilleri MMP pilot (25 November)
- Gerald Farrugia Tug Malta tug master (25 November)
- Henry Cutajar Tug Malta tug master (25 November)
- Colin Formosa MMP pilot (26 November)
- Carmel Sciluna MMP pilot (26 November)
- Joseph Brincat MMP pilot (26 November)
- Denis Cassar Tug Malta tug master (26 November)
- Carnel Bonnici Tug Malta tug master (26 November)
- John H. Dalli MMP pilot (27 November)
- John Tua MMP pilot (27 November)
- Alan Brown MMP pilot (27 November)
- Raymond Azzopardi Tug Malta tug master (27 November)
- Kenneth Grima Tug Malta tug master (27 November)
- Capt. Cees van de Vrie MARIN instructor (former pilot Western Scheldt area)
- Johan Dekker MARIN project manager

On 28 November the MARIN staff had the opportunity to visit Marsaxlokk Port and experience the wave conditions just outside the breakwater that a SE wind can generate (arrivals to the port had been suspended due to the weather).

An advantage of the participation of many different pilots is that the variation of the human factor is included in the simulations: each pilot will make the manoeuvre differently, depending on his skills and experience. A drawback, however, is that the first run of each pilot is a new start of the learning curve for this specific manoeuvre. To overcome the latter as much as possible, MARIN's instructor briefed the participants after the first day regarding the experience gained from the previous days and gave them guidelines on how the manoeuvre could best be carried out.

3.2 Bridge setup

The study was carried out using MMRTC's Full-Mission Bridges 1 and 2 (FMB1 and FMB2). FMB1 was used to sail the LNG carrier, while FMB2 was the used to command the free-sailing tug. The other tugs were controlled from the instructor station by the pilot operating the simulator.

FMB1 (see Figure 3-1) has a 210° visual projected scenery, with additional rear view on a large screen. Two additional monitors mounted horizontally left and right provide the view from the bridge wing down, which can be useful when berthing to the quay or – in this case – alongside the FSU.

The visuals usually show the view from the centre position of the bridge, but the viewpoint can also be switched to the port side or starboard side bridge wing position, e.g. when manoeuvring close to the berth. This provides the pilot a better view to judge the ships heading in relation to the alignment of the berth and estimate the distance.

Figure 3-1 View Full-Mission Bridge 1 during one of the runs

For the project, MMRTC's standard bridge setup was used on FMB1 in which the console was equipped with:

- Telegraph and rudder controls
- Control for the bow thruster
- A conning display showing the forward speed, the lateral speed fore and aft, the rate of turn, the setting of the engines, rudders and thrusters, wind speed and direction, under keel clearance etc.
- ARPA radar,
- An ECDIS display showing the nautical chart of the area
- A number of overhead indicators showing several parameters such as rudder angle
- VHF equipment for communication with FMB2 and with the instructor (for e.g. tug orders).

Figure 3-2 Displays on the bridge: ECDIS (left), conning (centre) and ARPA radar (right)

The free-sailing tug was operated on FMB2 by tug masters from Tug Malta. Each day two were available to steer the tug, who took turns on operating the tug. FMB2 (see Figure 3-3) has also a 210° visual projected scenery and additional rear view on a large screen. The bridge is equipped with ASD controls to operate the propulsion units and displays similar to FMB1, except for the overhead indicators which are not installed on FMB2.

Figure 3-3 View Full-Mission Bridge 2 during one of the runs

3.3 Simulation procedure and programme

The scenario to be simulated for each run was selected from the run program and the run was set up. The scenarios were varied to avoid that the same pilot would carry out the same manoeuvre under the same conditions twice within a short time. One of the pilots carried out the manoeuvre on the LNGC, while one of the tug masters operated the free sailing tug. The other tugs were operated by one of the pilots at the instructor station allowing for realistic time delays for execution of the orders.

Arrival runs were usually stopped when the vessel was under control (nearly stopped) in a position close to the FSU. Connecting the mooring lines and final berthing were not simulated as this saves time, so that more runs can be done. It was ensured that the LNGC was well under control with a small lateral speed before stopping the run. Departure runs were stopped when the vessel was under control and heading for open sea.

During the simulations, a total of 21 runs was carried out. As the current field needed to be manually adapted at the start of the run and the wind and wave conditions were also reduced in several runs from the default values included in the scenarios, the metocean conditions differ from run to run. Table 3-1 below summarizes the wind, wave and current conditions for each run.

Table 3-1 Summary of the simulation programme

Run nr	Manoeuvre	Current (approach)		Wind		Waves in the approach			
						sea		Swell	
		direction	speed	direction	speed	direction	Hs	direction	Hs
		[°N to]	[m/s]	[°N fr]	[m/s]	[°N fr]	[m]	[°N fr]	[m]
9	arrival	-	-	150	10	150	2.3	295	1
10	departure (emerg)	180	1.0 / 0.0	270	14	270	0.5	220	1.7
11	arrival	225	0.5	150	10	150	2.3	295	1
12	arrival	180	1	150	14	150	3.2	295	1.5
13	arrival	45	0.5	180	10	180	2	300	1.5
15	arrival	225	1.0 / 0.5	270	14	270	0.5	220	1.7
16	arrival	225	0.5	270	14	270	0.5	220	1.7
17	arrival	45	0.5	180	12	180	2.5	300	1.2
18	departure	-	-	180	14	180	2.5	300	1.5
19	arrival	180 / 225	0.5	150	12	150	2	295	1
20	arrival	180	0.5	180	12	180	2	300	1.5
21	arrival	225	0.5	300	12	300	0.5	220	1.7
22	arrival	45	0.5	180	12	180	2	300	1.5
24	departure	45	0.5	150	12	150	2.3	295	1.5
25	arrival (emerg)	225	0.5	150	12	150	2	295	1
27	arrival	225	0.5	270	12	270	0.5	220	1.7
28	arrival	180 / 225	1. → 0.25	180	12	180	2	300	1.5
29	arrival (emerg)	180 / 225	0.5	270	12	270	0.5	220	1.7
30	arrival (emerg)	225	0.5	150	12	150	2	295	1
31	arrival (emerg)	225	0.25	180	12	180	2	300	1.5
33	arrival	225	0.5	180	14	180	2.5	300	1.5

Upon completion of the run the results were briefly discussed and the MARIN instructor made notes regarding the runs. These notes are included in Appendix B. Figure 3-4 and Figure 3-5 show snapshots of some the manoeuvres performed during the study.

Figure 3-4 View of the LNGC approaching the port in one of the runs

Figure 3-5 View of the LNGC manoeuvring near the FSU in one of the runs

3.4 Observations

During the simulations the MARIN instructor made notes of the remarks from the pilots and at the end of each day the results were discussed with the participants. Based on their professional experience, the participating pilots/captains had the following views and remarks concerning the tested situations:

Manoeuvring strategy arrival
The arrival manoeuvre consists of three phases: approach, turning and berthing. Two tugs make fast outside the port and are connected at the aft and forward centre leads during the approach.

Approach: The vessel transits at minimum steering speed which corresponds with 6 knots through the water (this varies from ship to ship, but 6 kt is a typical value). Once connected, the stern tug can be used to control the speed. When passing the breakwater the speed should not exceed 4 knots.

Turning: The third and fourth tug connect in the final part of the approach on the starboard side shoulder and quarter if weather permits. Once inside the harbour basin the vessel is stopped in about 1.5 times the ships length and turned over port, away from the FSU. This port turn also provides the maximum manoeuvring space in case the vessel drifts towards the North or Northwest in Southerly or South-easterly winds and/or waves. By turning over port side, the vessel also creates lee for the two tugs in the side.

Berthing: The vessel is then manoeuvred astern over a distance of about twice the ship's length and finally brought parallel in line with the FSU assisted by the four tugs. The vessel berths bow out. The berthing and side stepping towards the FSU is fully controlled by the tugs and bow thruster. Longitudinal speeds are corrected using the main engine. During mooring the tugs keep the vessel in position.

Manoeuvring strategy departure
Departures are fairly straightforward due to the geometry of the port. The vessel is berthed bow out. The four tugs manoeuvre the vessel clear of the FSU. The vessel sets sail and the two side tugs are disconnected. The tugs on the forward and aft centre lead remain connected until the vessel is well clear of the Benghajsa Reef south of the harbour entrance.

Limiting conditions
For the arrival manoeuvre the limiting wind speed is 12 m/s from any direction. Departures could well be carried out at the maximum tested condition of 14 m/s.

For waves the ability for the tugs to operate is the limiting factor. This depends to some extent on the skills and experience of the tug master, but there was consensus that in waves over Hs = 2 m the tugs may be able to connect, but are generally not able to offer much assistance due to the risk of breaking the tow line.

Most of the simulations were carried out with a cross-current of 1 kt, though at the start of the run the current speed was occasionally higher. The current of 1 kt did not cause any problems.

To allow implementation of these limits, actual information regarding waves and current is indispensable. The current information allows a pilot to anticipate on the actual conditions, whereas the wave data can be used as an unambiguous reference to decide whether the manoeuvre can be safely carried out or not. Installation of a wave / current buoy at a suitable location with continuous (e.g. every 10 or 20 minutes) transmission of the measurements is recommended. It may be possible to present these measured data on the PPU of the pilot.

Tugs

The manoeuvres should be carried out using four tugs. Two tugs are required during the approach; two more are required to control the ship when turning, backing up towards the jetty and when berthing alongside the FSU. The capacity of the tugs as used in the simulations (one 80 t BP and three 70 t BP) is sufficient to control the LNGC under the tested conditions.

4 PRESENTATION, ANALYSIS AND DISCUSSION OF RESULTS

4.1 Evaluation criteria

To analyse the safety of the manoeuvres, the runs made on the manoeuvring simulator are analysed regarding the controllability and the used space. Plots of several relevant parameters during the run are used for this evaluation, either by obtaining certain characteristic values from it or by scoring a parameter. The parameters and criteria used as indicators for these aspects are described in the following sections.

4.1.1 Controllability of the manoeuvre

The controllability of the manoeuvre is usually assessed by evaluating the use of the steering tools of the ship (rudder/propeller, bow/stern thrusters and tugs). The general principle is that in normal operations sufficient margin (reserve capacity) must be available to handle unexpected events such as sudden gust in the wind or human errors (e.g. by misinterpretation of a command by the helmsman or tug master).

Criterion for engine use

During the approach and berthing the use of the main engine should not exceed “Half” for more than 2 minutes. If this criterion is exceeded, quite large forces are apparently needed to control the vessel, which is considered not appropriate for a controlled and safe manoeuvre.

Criterion for rudder and propeller: the safety index

As a high rudder angle with a low propeller speed has the same steering effect as a smaller angle with high propeller speed, a parameter combining the two has been developed. This parameter, referred to as safety index SI, gives the ratio of the actual rudder angle and engine force relative to a criterion for a safe combination of rudder angle and engine force. The criterion is selected in such a way that a sufficiently large reserve of steering force is available to cope with unexpected situations that may occur in practice.

For conventional seagoing vessels, the adopted criterion for safe manoeuvring is a rudder angle of 20 degrees (for a maximum rudder angle of 35 degrees) at a propeller speed corresponding to “Half Ahead” (HaH). As the steering force is proportional to the square of the propeller speed, the safety index is defined by

$$SI = \frac{\delta \cdot rpm^2}{20 \cdot rpm_{HaH}{}^2} \qquad \text{for } rpm > 0$$

$$SI = \frac{rpm^2}{rpm_{HaH}{}^2} \qquad \text{for } rpm < 0$$

In which δ is the rudder angle and *rpm* the propeller speed.

For a free sailing vessel, the usual criterion for the safety index, e.g. when sailing through a channel, is 1. A performed manoeuvre is considered to be safe and well controlled if the safety index exceeds the value of 1 only for short durations. For seagoing vessels, a maximum duration of 2 minutes is used. This allows giving short power bursts for instantaneous correction of the ship, but excludes situations with prolonged use of a high rudder angle at high engine power.

Bow and stern thrusters
To allow some margin for error and safety, the bow and stern thrusters should not be used at maximum capacity for a long time during the considered manoeuvre. The power of the thruster should not exceed 70% of their nominal capacity for more than 2 minutes. As the power is proportional to the square of the propeller speed, the propeller speed should not exceed 83.7% of the maximum propeller speed. As the maximum propeller speed is 300 rpm a limit of 250 rpm was used to evaluate the use of the thruster. Thruster use is considered to be “very safe”, if the power does not exceed 50% of the capacity of the thrusters. This corresponds to a propeller speed for the bow thrusters of 210 rpm.

Tugs
The standard approach to evaluate the use of the tugs in manoeuvring simulations is to compare the force delivered by the tugs with the maximum bollard pull that the tugs can provide, similar to the approach for evaluating the use of the bow thruster: the required force of the tug should not exceed 70% of the nominal capacity for more than 2 minutes. For the instructor-operated tugs this criterion can be directly applied as the force is directly available as output from the run.

For the free-sailing tug the forces in the line load vary largely due to the motions of the tug in waves. Evaluating the line force is therefore not well possible and the required power from the propulsion is therefore evaluated. The power is proportional to the square of the propeller speed, so the propeller speed should not exceed 83.7% of the maximum propeller speed. As the maximum propeller speed of the free-sailing tug in the simulations is 200 rpm, the 83.7% corresponds to 167 rpm.

Combination of thrusters and tugs
To control the ship while manoeuvring at low speeds inside the harbour, a combination of the tugs and the thruster(s) of the ship can be used. When manoeuvring in the harbour once the ship has been stopped, the tugs and thruster are mainly used to control the rate of turn and the lateral motion of the ship. When relevant, the total realised force must be evaluated in relation to the total capacity (thruster and tug) at bow and stern of the ship.

4.1.2 Space used
For the used space the clearance to the sides of the entrance channel and to other objects such as moored ships is most relevant. Using strict criteria for distances in the evaluation of manoeuvres is not always possible. In a well-controlled manoeuvre at low speeds, a fairly small distance may be acceptable whereas a much larger distance can be inadequate at high speeds. A distance of one beam of the vessel is usually considered a safe distance for manoeuvring of a ship without tugs. If the ship is assisted by tugs, there must be sufficient space to manoeuvre with the tugs. This depends on the configuration of the tugs. If the vessel is assisted by a tug operating on the side of the vessel, more space is required than for tugs on the centre leads.

For the present study the used space has been judged by visual inspection of the plots of the sailed track. As Marsaxlokk port has a fairly wide entrance and ample space for manoeuvring in the area between Freeport Terminal 2 and the new LNG terminal, the distance to selected objects such as the breakwater head, buoys and moored vessels and the distance to the 10 m depth contour were verified when the trackplot showed that the LNGC came fairly close to one of these.

4.2 Presentation of results

4.2.1 General

The results of the simulations are stored in a database, which includes the realisation of a large number of parameters as function of time (from the start until the end of the run). The database includes data regarding the position, heading, speed, engine and rudder setting of the ship, but also the external forces acting on the ship due to wind, waves, bank suction and tugs. Upon completion of all simulations the data from the runs were retrieved from the MMRTC simulator and further analysed at MARIN to evaluate the feasibility and safety of the considered manoeuvres. The focus of the analysis is on the controllability of the vessel and the space used during the manoeuvres.

4.2.2 Plots

The results of each run are presented in a number of plots:

- Plots of the sailed track on the map representation of area (trackplots)
- Plots of a number of characteristic parameters presented as function of time (dataplots).

The plots showing parameters as function of time are used to evaluate some parameters, as also the duration of exceeding certain limits is relevant.

The trackplots of the runs are shown in Appendix C. The interval between two ships can be set at the instructor position. Usually a 1 minute interval is applied, but it may be varying in the runs.

The data plots as function of time are included in Appendix D. The following plots are presented for each of the runs (in which x indicates the run number):

x.a Data plot showing the forward (SoG and STW) and transverse speed, heading, course over the ground (CoG) and rate of turn of the sailing ship. Note that a positive transverse speed and rate of turn is to starboard, a negative value to port.

x.b Data plot showing the propeller speed, the rudder angle, the safety index (see Section 4.1.1) and, if applicable, the use of the bow thruster.

x.c Data plot for (instructor operated) tugs 1 & 2 showing total tug force, direction of tug force (relative to the vessel; with 0° is ahead, 90° to SB, 180° (or 180°) astern and -90° to PS) and two subplots with x- and y-coordinates on the ship where the tug is connected as this sometimes is changed during the run. Positive number mean on SB or forward from the midships; negative values the opposite.

x.d Data plot for (instructor operated) tugs 3 & 4 showing total tug force, direction of tug force and position on the ship where the tug is connected.

x.e Data plot showing force in and direction of the tow line, forward speed, propeller speed and thruster angle of the free-sailing tug

x.f Data plot showing environmental conditions during the run: wind speed and direction (coming from); significant wave height and direction (coming from) and current speed and direction (going to).

The tick interval on the horizontal axis of the dataplots is 4 minutes.

Examples of these plots are shown in Figure 4-1 to Figure 4-6. Note that the tugs are not always connected at the same point on the assisted ship. The coordinates where the tug is connected are included in the plots, but for easy reference the position is also described in the summary tables in Section 4.4.

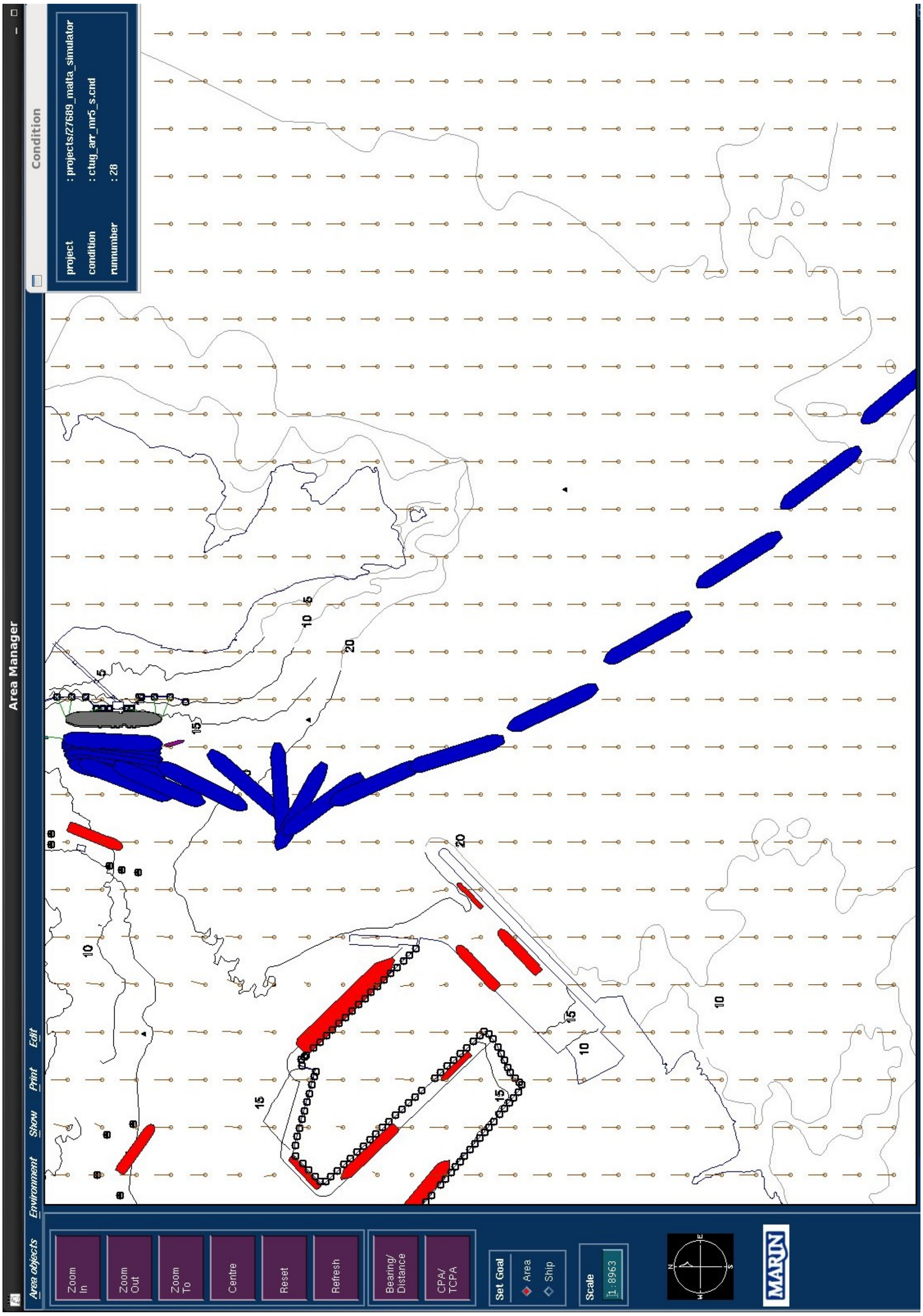
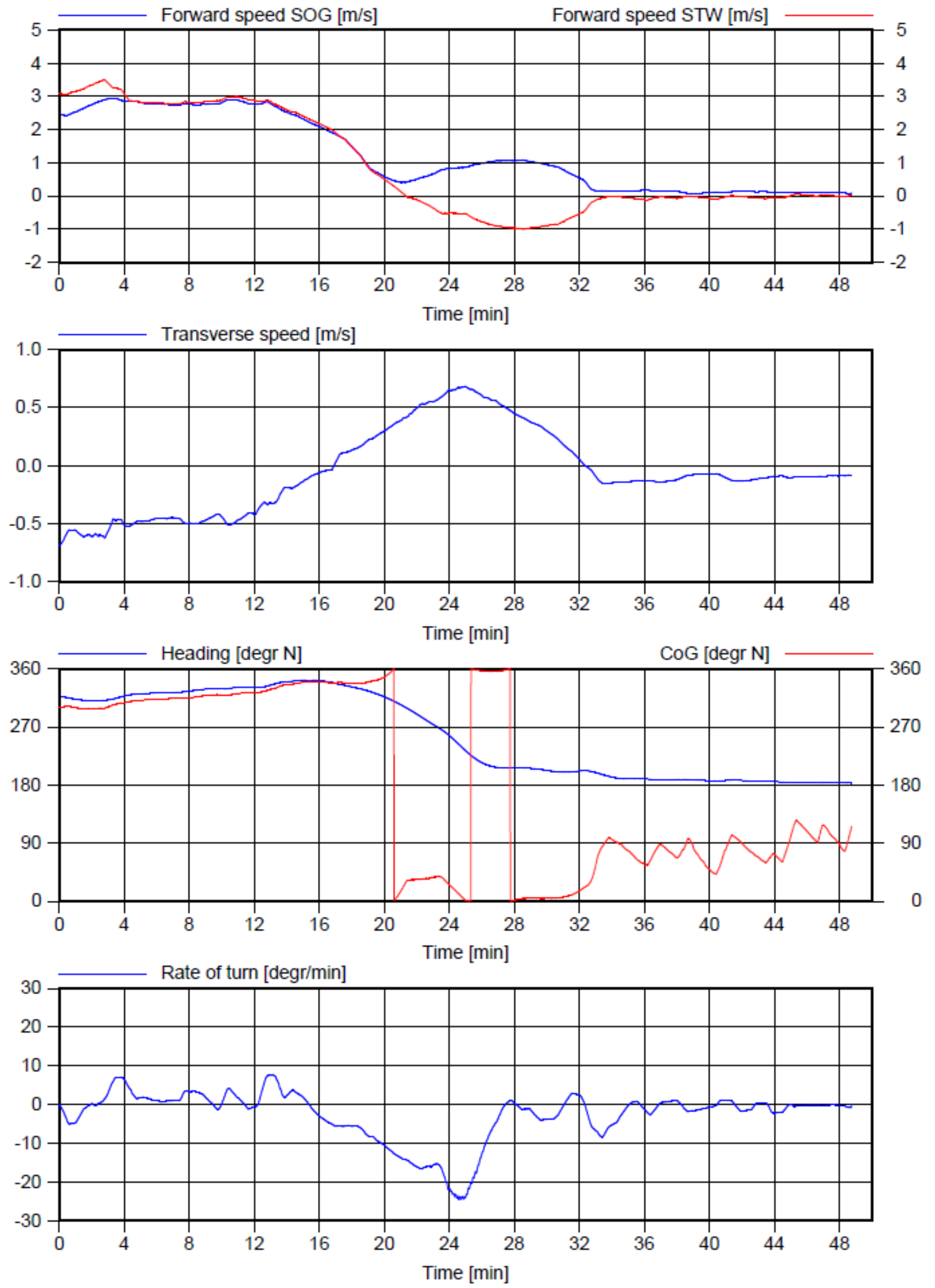
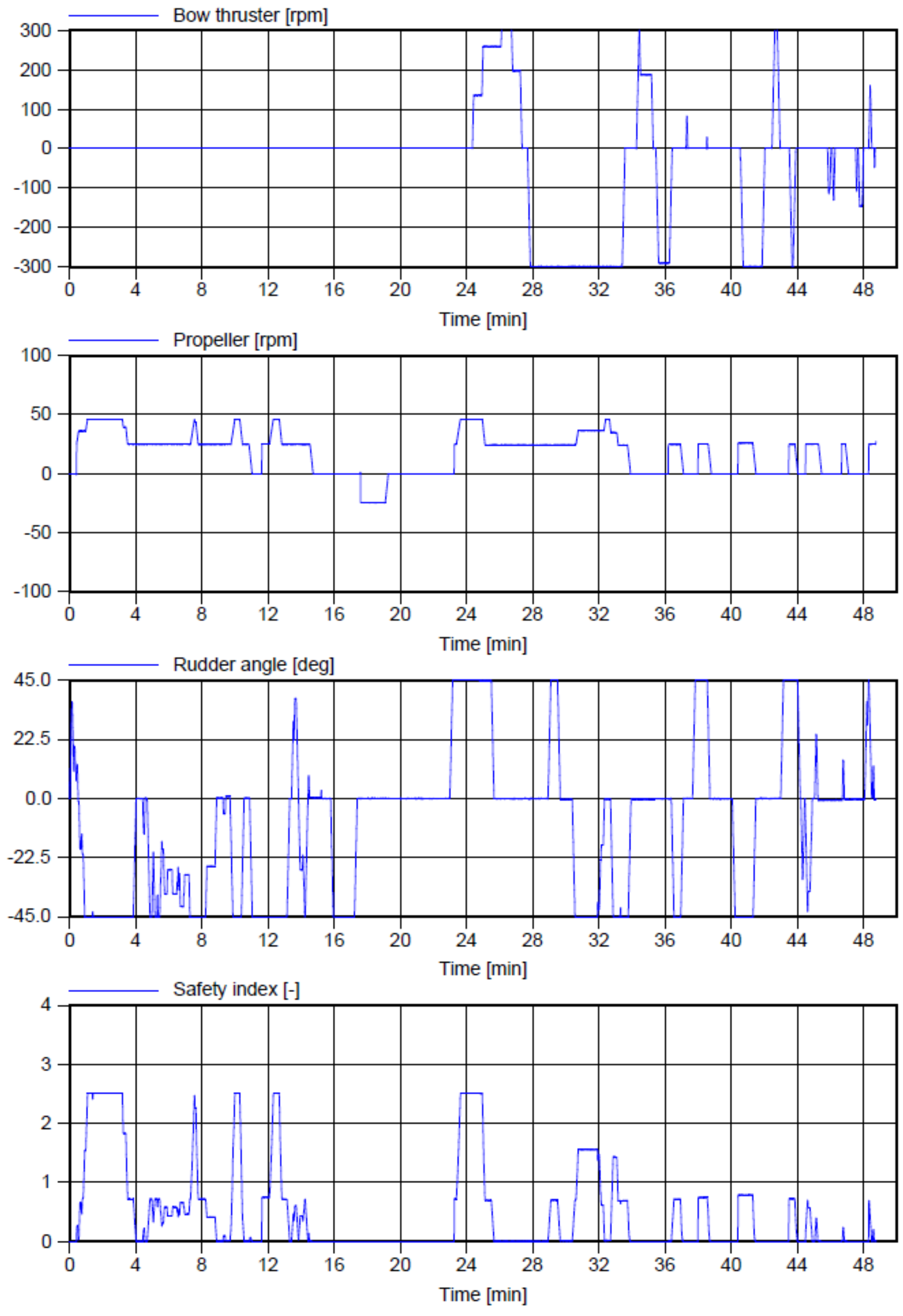


Figure 4-1 Example of track plot for an arrival manoeuvre (run 11)



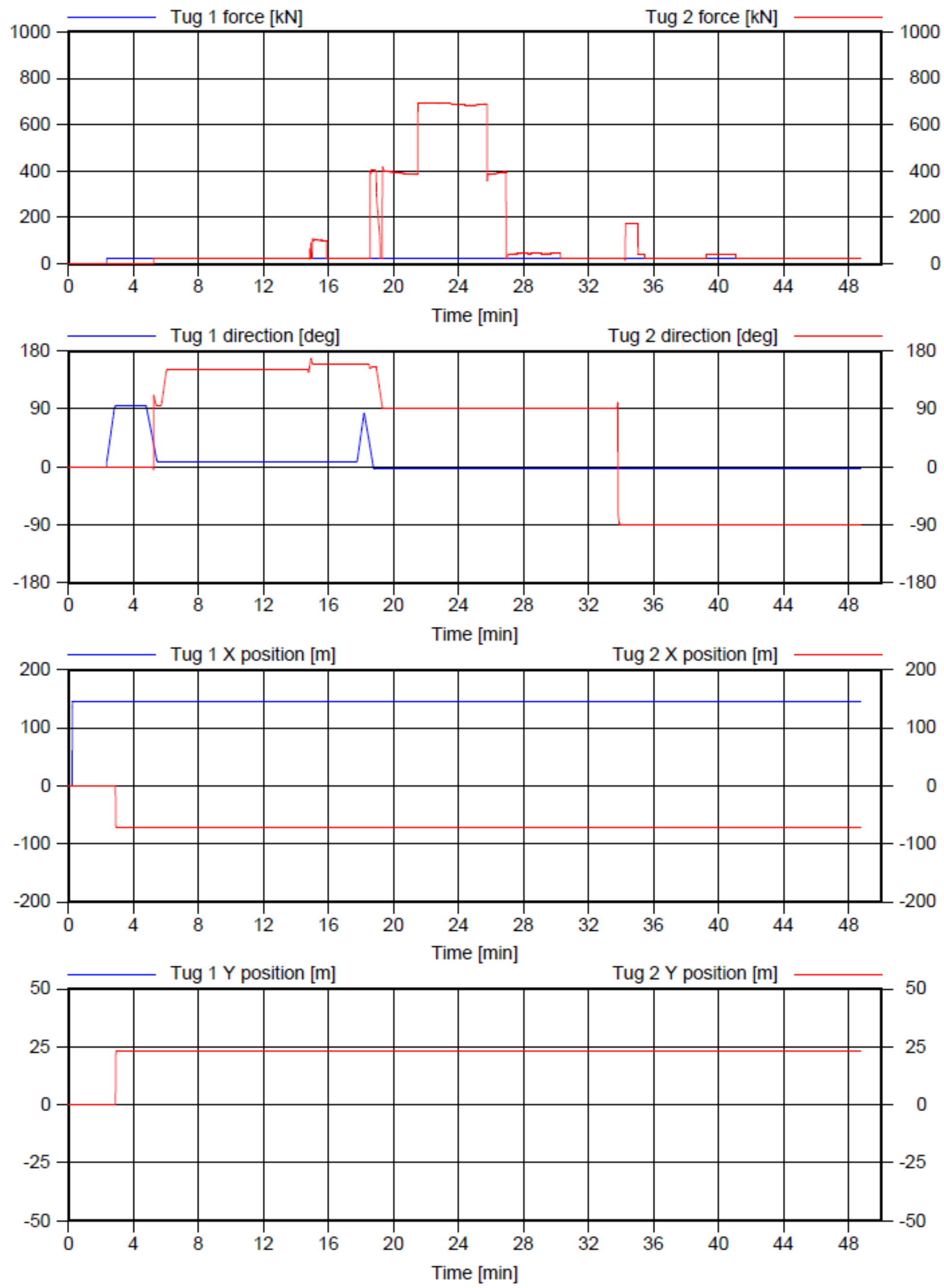
Run: 28	Malta
Arrival	Wind 12m/s from S
MARIN's Nautical Centre MSCN	Fig. 17.a

Figure 4-2 Example of data plot showing velocities, heading and rate of turn of the sailing ship



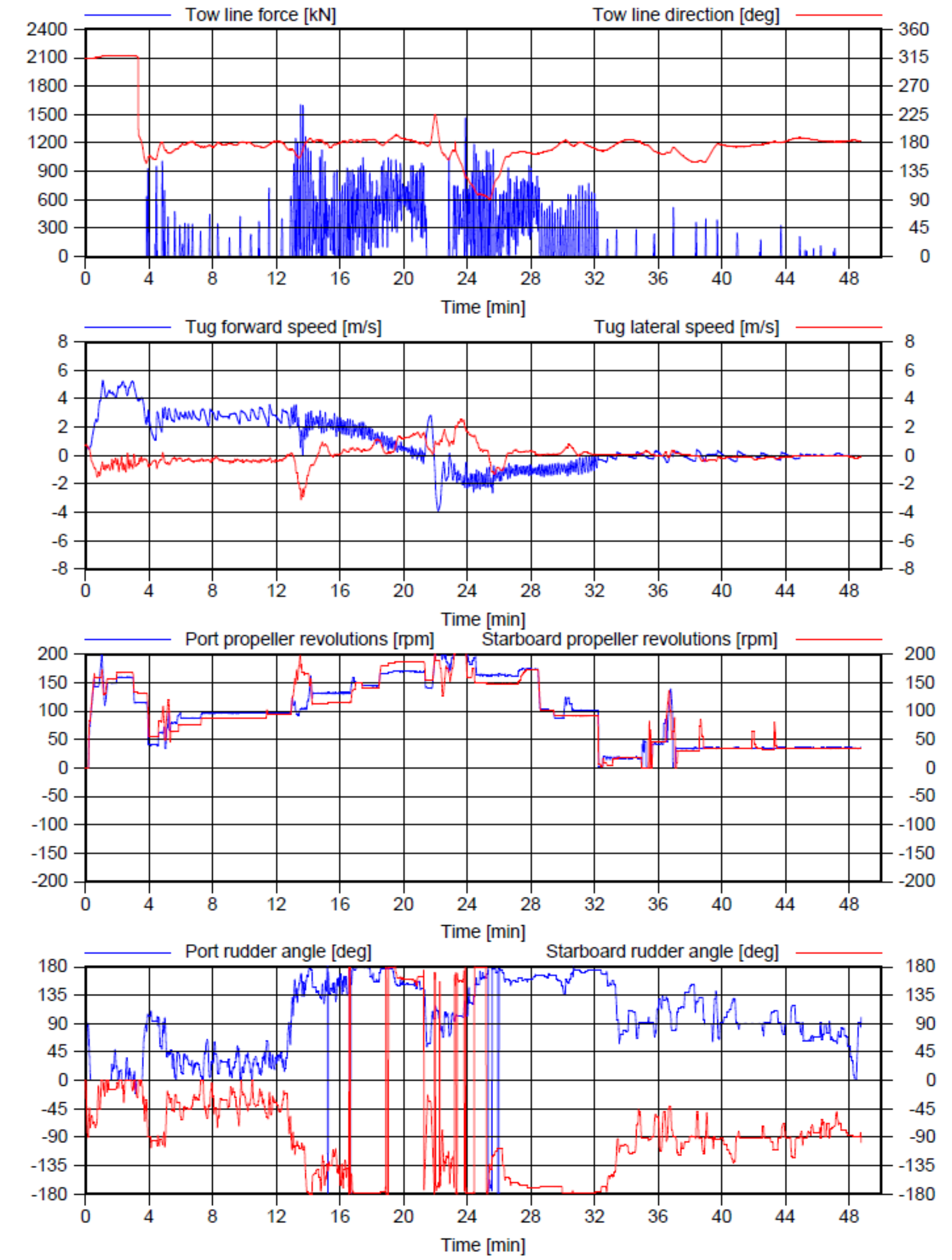
Run: 28	Malta
Arrival	Wind 12m/s from S
MARIN's Nautical Centre MSCN	Fig. 17.b

Figure 4-3 Example of data plot showing propeller, rudder and (if used) bow thruster use of the sailing ship



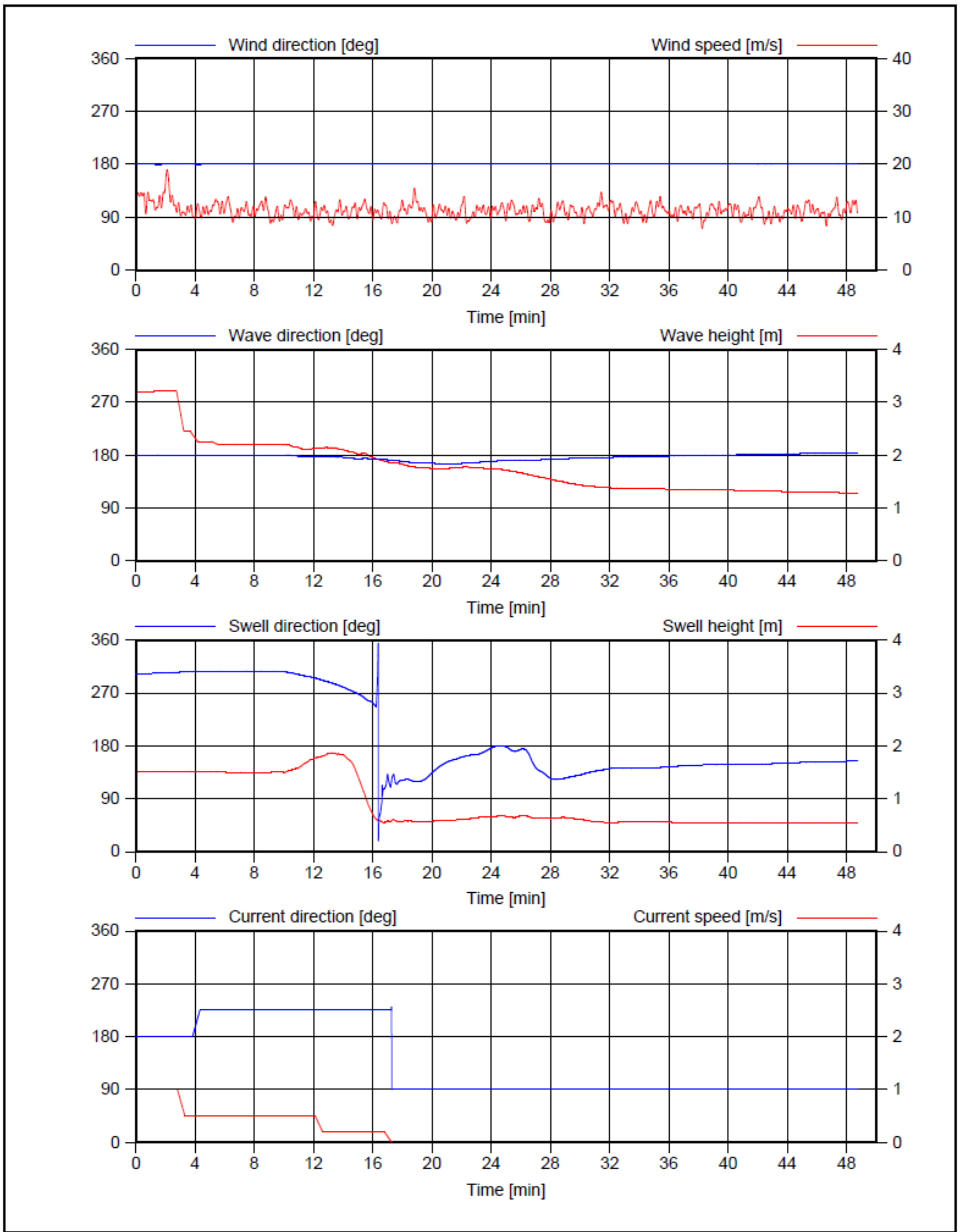
Run: 28	Malta
Arrival	Wind 12m/s from S
MARIN's Nautical Centre MSCN	Fig. 17.c

Figure 4-4 Example of data plot showing the tug data



Run: 28	Malta
Arrival	Wind 12m/s from S
MARIN's Nautical Centre MSCN	Fig. 17.e

Figure 4-5 Example of data plot showing parameters of the free-sailing tug



Run: 28	Malta
Arrival	Wind 12m/s from S
MARIN's Nautical Centre MSCN	Fig. 17.f

Figure 4-6 Example of data plot showing the metocean data

4.3 Analysis

To support the analysis of the runs, the controllability of the vessel and the space used has been established by obtaining characteristic values and by visual evaluation of the plots. The use of main engine/rudder and bow thrusters has been evaluated by considering the plots of the safety index and bow thrusters rpm. Combined criteria for magnitude and duration have been applied as given in Table 4-1. Different parameters were considered as described in Section 4.1.

Table 4-1 Criteria used to score the controllability of the vessels

Engine use	Safety Index	Bow thruster	Score	Description
≤ 'Slow'	≤ 0.7	≤ 210	++	very safe
≤ 'Half' or > 'Half' for less than 1 min	≤ 1 or >1 for less than 1 min	≤ 250 or >250 for less than 1 min	+	safe
≈ 'Half' for more than 2 min or > 'Half' for less than 2 min	≈ 1 for more than 2 min or >1 for less than 2 min	≈ 250 for more than 2 min or >250 for less than 2 min	o	at the limit, just safe
> 'Half' for more than 2 min	>1 for more than 2 min	>250 for more than 2 min	-	unsafe

4.4 Discussion of results

4.4.1 Arrival wind & waves from SE (run 9, 11, 12, 19 and 25)

In total 6 arrival runs were carried out for wind from 150°N, including 2 runs with an emergency. Table 4-2 summarizes the metocean conditions in these runs; the runs with an emergency are shaded. In run 25 the maximum power of the stern tug was reduced to 30% to simulate an emergency, but as the runs was completed normally, the run has been included in the analysis of the normal runs.

Table 4-2 Metocean conditions in the arrival runs for wind from 150°N

Run nr	Current (in approach)		Wind		Sea waves		Swell waves	
	direction	speed	dir.	speed	dir.	sig. height	dir.	sig. height
	[°N to]	[m/s]	[°N fr]	[m/s]	[°N fr]	[m]	[°N fr]	[m]
9	-	-	150	10	150	2.3	295	1
11	225	0.5	150	10	150	2.3	295	1
12	180	1	150	14	150	3.2	295	1.5
19	180 / 225	0.5	150	12	150	2	295	1
25	225	0.5	150	12	150	2	295	1

Controllability

The controllability of the LNGC during the manoeuvre has been evaluated by visual inspection of the dataplots. The used power of the main engine, the safety factor for steering, the use of the thrusters and the tug forces were compared with the criteria and rated using the criteria in Table 4-1. These scores are summarized in Table 4-3. As the position where each tug is connected varies from scenario to scenario, the position where each tug is connected is also indicated in the table. Note that the tugs are sometimes at another position when the run starts up, but the instructor repositioned them to the position indicated by the pilot. In some runs the position changes during the run; this is indicated in the table. For reference the rating by the simulator supervisor (see last column of the table in Appendix B) is also included in Table 4-3 by a colour.

Table 4-3 Evaluation of controllability in the arrival runs for wind from 150°N

Run nr	Rating instr.	Score ME power	Score safety index	Bow thruster Max. rpm	Bow thruster Score	Tug 1 Connect. to	Tug 1 Max. force	Tug 1 Score	Tug 2 Connect. to	Tug 2 Max. force	Tug 2 Score	Tug 3 Connect. to	Tug 3 Max. force	Tug 3 Score	Tug 4 Connect. to	Tug 4 Max. force	Tug 4 Score	Free tug Connect. to	Free tug Score	Overall score	Run duration
		[-]	[-]	[rpm]	[-]		[kN]	[-]		[kN]	[-]		[kN]	[-]		[kN]	[-]		[-]		[min]
9	+	+	+	0	++	CL bow	450	+	CL aft	700	-	SB bow	700	0	not connected			SB aft	+	+	44
11	-	++	++	190	++	CL bow	800	-	SB aft	700	-	SB bow	700	-	not connected			CL aft	-	-	47
12	+/-	+	+	300	+	CL aft	800	+	SB aft	570	+	SB bow	700	-	not connected			CL bow	-	-	36
19	+	+	+	300	-	CL aft	800	--	SB bow	700	+	SB aft	700	0	not connected			CL bow	+	+/-	46
25	+	+	+	300	0	CL aft	560	+	SB bow	700	-	SB aft	700	-	not connected			CL bow	0	+	44

It can be seen that the use of engine and rudder is within the criteria for a safe manoeuvre. The use of bow thruster or tugs is sometimes “unsafe”, but where (position at LNGC) or when (phase of the manoeuvre) this occurs varies from run to run:

- In run 9 (very first run, familiarisation) the stern tug is used to slow down the LNGC rapidly upon after the start of the run. Later the speed is increased again, so using the stern tug at maximum power for about 3 minutes was not necessary. The stern tug is also used at maximum power while turning the LNGC and to get astern speed for manoeuvring towards the terminal quickly. When manoeuvring near the berth the use of the all four tugs is within the criteria for a “safe” run.
- In run 11 the use of all tugs is “unsafe”. This occurs when the vessel turns inside the harbour and when the ship is pulled/pushed sideways towards the FSU over a fairly long distance. This may be related to the fact that the LNGC is turned over SB. Due to the high speed when starting the turn (about 6 kn) in combination with the SE wind and waves, the LNGC drifts far into the port and the manoeuvre is not well controlled. According to the pilot the high speed upon entering the port was caused by the fact that the stern tug was connected too late. This underlines the necessity of connecting the stern tug early enough during the approach.
- In run 12 the tug at the SB bow is used at maximum power for a little bit longer than the criterion for “safe” to gain some sideways speed to berth the LNGC alongside the FSU; shortly later the same tug is used in opposite direction to reduce the lateral speed again. The free-sailing tug (connected at the bow) is used over the criteria for “at the limit” when the turn to SB is made once the ship is inside the port. The tug is pulling to SB at the bow to reverse the turn to PS into a turn to SB, while the stern tug is pulling to PS. As the speed is still about 4.5 kn, a short kick off the main engine with the rudder hard over would probably have been more effective to initiate the turn to SB than pulling at the bow. At 14.55 minutes after the start of the run, the line of the free-sailing tug fails. The motions of the tug in combination with the load put on the line lead to large dynamic variations in the line load. Once the tug is reconnected the
- In run 19 the stern tug used at maximum power for 6 minutes to stop the LNGC quickly once it is inside the port. By using the main engine a bit longer astern or by starting to slow down earlier, less tug force would be needed. The bow thruster is used at maximum power for 3-4 minutes when turning. Once manoeuvring astern towards the FSU all tools are used within the criteria for “safe”.
- In run 25 the two tugs in the side of the vessel are used at high power to bring the LNGC parallel to the FSU and push it alongside. The high power appears to be mainly for speeding up the manoeuvre. When the tugs stop pushing the lateral speed remains steady and is not reduced by the wind forces. This shows that the manoeuvre can also be carried out with lower tug forces. The tug at the SB bow is also used at high power for several minutes when turning the vessel.

- Run 30 is an emergency (black-out LNGC), but as the anchor is used to stop the vessel, all tugs are used within the criteria for a safe manoeuvre.

Used space
Marsaxlokk port offers sufficient manoeuvring space for the LNGC so that the runs are mostly carried out with good clearance to all sides. In run 11 the LNGC drifts significantly more than planned, but the stern is still about a ship's width from the grounding line. In run 9 the stern of the LNGC is a similar distance from the west cardinal buoy opposite the breakwater, but this is mainly because in this first run the turn was made a bit too early.

Discussion and conclusion
The two runs in which the turn was made over SB were less successful than the runs in which the LNGC turned over PS. The latter is therefore preferred. In run 12 the line of the bow tug is snapping during the manoeuvre. This is due to the high waves inside the port. The wave conditions in this run are considered to be over the limit for safe operations for the tugs.

The results of the simulations show that in the successful runs the use of tugs and/or bow thruster is over the criteria for a safe manoeuvre, but this is in parts of the manoeuvre where this is not critical for the manoeuvre. If the tugs would have been used at lower power, the manoeuvre would have taken a bit longer, but would not have been out of control. This confirms the conclusion from the debriefing that the arrival manoeuvre can be carried out for wind speeds up to 12 m/s and significant wave heights up to 2 m.

4.4.2 Arrival wind & waves from S (run 13, 17, 20, 22, 28 and 33)
In total 7 arrival runs were carried out for wind from 180°N, including 1 run with an emergency. Table 4-4 summarizes the metocean conditions in these runs; the run with an emergency is shaded.

Table 4-4 Metocean conditions in the arrival runs for wind from 180°N

Run nr	Current (in approach)		Wind		Sea waves		Swell waves	
	direction	speed	dir.	speed	dir.	sig. height	dir.	sig. height
	[°N to]	[m/s]	[°N fr]	[m/s]	[°N fr]	[m]	[°N fr]	[m]
13	45	0.5	180	10	180	2	300	1.5
17	45	0.5	180	12	180	2.5	300	1.2
20	180	0.5	180	12	180	2	300	1.5
22	45	0.5	180	12	180	2	300	1.5
28	180 / 225	1. → 0.25	180	12	180	2	300	1.5
33	225	0.5	180	14	180	2.5	300	1.5

Controllability
The controllability of the LNGC during the manoeuvre has been evaluated by visual inspection of the dataplots. Table 4-3 summarizes the results.

Table 4-5 Evaluation of controllability in the arrival runs for wind from 180°N

Run nr	Rating instr.	Score ME power	Score safety index	Bow thruster Max. rpm	Bow thruster Score	Tug 1 Connect. to	Tug 1 Max. force	Tug 1 Score	Tug 2 Connect. to	Tug 2 Max. force	Tug 2 Score	Tug 3 Connect. to	Tug 3 Max. force	Tug 3 Score	Tug 4 Connect. to	Tug 4 Max. force	Tug 4 Score	Free tug Connect. to	Free tug Score	Overall score	Run duration
		[-]	[-]	[rpm]	[-]		[kN]	[-]		[kN]	[-]		[kN]	[-]		[kN]	[-]		[-]		[min]
13	+/-	+	+	0	++	CL bow	800	-	SB aft	700	0	SB bow	700	-	not connected			CL aft	-	+/-	41
17	+/-	+/-	+	300	+	CL aft	800	-	SB bow	660	-	SB aft	660	-	not connected			CL bow	-	-	42
20	+	+	+	150	++	CL bow	800	+	SB bow	700	+	SB aft	700	--	CL aft	980	--	not connected		+/-	58
22	+/-	+	+	300	+	CL bow	800	-	SB bow	400	+	SB aft	660	+	not connected			CL aft	0	+/-	48
28	+	-	-	300	-	CL bow	0	++	SB aft	700	-	SB bow	700	+	not connected			CL aft	0	+	49
33	+	+	0	300	--	CL bow	0	++	SB aft	430	+	SB bow	485	+	CL aft	870	0	not connected		+	43

The criteria for the use of main engine and rudder are only exceeded in run 28. This occurs at the start of the run and is related to the fact that the current was initially too strong: 1 m/s (2 kn) instead of 0.5 m/s (1 kn) and going south instead of southwest. When the current was reduced the use of main engine and rudder was within the criteria.

As for the runs with wind from 150°N, in each run one or more of the tugs is used over the criteria for “safe”.

- In run 13 the bow tug is used over the criteria when turning upon arriving in the port (4 minutes maximum power) in order to turn the ship rapidly. When sailing astern to the terminal, the tug on the SB bow is used to control the heading of the ship. The tug is either pushing or pulling at maximum power, leading to fairly large variations in heading and rate of turn (from +15 °/min to -15 °/min). This is not necessary to compensate external forces as the wind is on the bow in this part of the manoeuvre. A more modest use of this tug would have made the manoeuvre smoother without compromising the safety.
- In run 17 the speed of the vessel when entering the port (nearly 7 kn) is too high for a safe manoeuvre. To stop the ship, more than half astern is required for about 2 minutes and while the stern tug is at (nearly) maximum power for about 5 minutes. After turning the LNGC ends fairly far from the FSU and needs to move 200-250 m in lateral direction. The two tugs in the side are used at fairly high power to speed this up, but these high forces (over the limit for “just safe”) are not to control the ship in these conditions. With lower forces the manoeuvre would have taken a bit longer. The pilot commented that the speed at the harbour entrance could have been better controlled if the run had started further out.
- In run 20 the two tugs at the stern are used over the limit for a safe manoeuvre when turning the vessel. The tug at the centre lead is used to control the speed in the approach. The force of 600 kN (approx 60 t) is a bit high, but this may be caused by the fact that the maximum force of this tug was more than expected (90 t instead of 70 t). Backing up to the terminal is well controlled; the pilot uses the stern tug to pull the vessel astern (at about 50 t), while the main engine is running ahead. As the rudder is not used to control the heading of the LNGC, this is not very energy efficient...
- In run 22 the CL bow tug is used at maximum power for 3-4 minutes to control the bow when turning. As the SB bow tug is used under the 70% criterion while the bow thruster is not used at all in this part of the manoeuvre, sufficient margin is available.
- In run 28 the SB aft tug is used at maximum power for about 4 minutes when the ship is stopped to increase the rate of turn. This is not required to keep the ship under control. The remainder of the manoeuvre is carried out smoothly using mainly the bow thruster and short kicks of the main engine. The tugs are hardly

used in the final part of the manoeuvre. As the wind is on the bow, they are not needed to counteract lateral forces.

- In run 33 the tugs are used with the criteria. Only the bow thruster is used at maximum force fairly long when turning the vessel. The tugs at CL bow and SB bow are not used up to the limit during this part of the manoeuvre, so that sufficient spare capacity remains available.

Used space

In runs 13, 20 and 22 the stern of the vessel is too close to the west cardinal buoy. In runs 13 and 20 this occurs because the turn is made too early, which can easily be avoided by starting the turn a bit further inside the port. In run 22 the NE-going current sets the LNGC too much from the track, so that the LNGC sails too close to the SB side of the port entrance. This is partly a simulator effect as the distance from the starting point of the run to the port is a bit short, but in run 17 the pilot was able to keep the vessel better on track under the same current conditions.

Discussion

Though one of the runs carried out for wind from 180°N was unsafe (run 17), the other runs carried out for this condition show that the manoeuvre can be safely carried out with sufficient margin with respect to the controllability of the manoeuvre. Though the tugs and bow thruster are sometimes used over the criteria for a safe manoeuvre, this was often to speed up certain parts of the manoeuvre (e.g. turning). If lower power would have been used the manoeuvre would have taken a bit longer, but would not have run out of control.

It seems that in run 17 the deviation to SB from the preferred track is caused by not well anticipating to the cross-current in the approach. This is partly caused by the fact that the starting position in the simulations is close to the port entrance and the pilot has little time to “feel” the situation and adapt the heading of the vessel. In reality the pilot has more time to respond to conditions and he will hence be able to ensure that the course over the ground of the vessel matches the orientation of the approach. It could, however, be useful for the pilot if he knows the current conditions in the approach when planning the entrance manoeuvre, so that he can anticipate and adapt is strategy, e.g. by estimating the required drift angle to compensate for the direction and magnitude of the current. This could be realised by installing a current meter at a suitable position outside the port.

To provide better reference for the position of the ship during the approach a leading line could be installed to mark the approach line through the centre of the port entrance, e.g. along a line parallel to the line marked by the south and west cardinal buoys on the NE side of the approach as indicated in Figure 4-7.

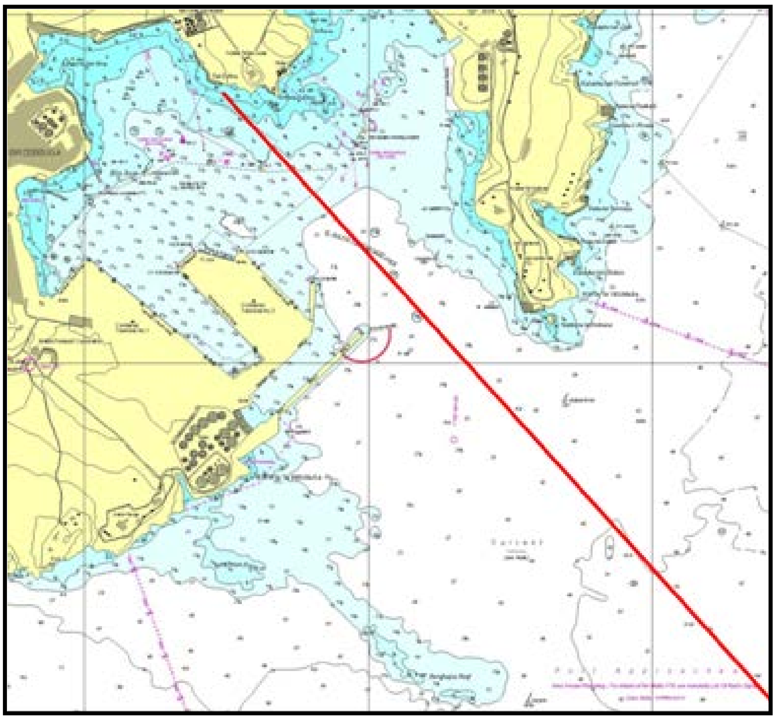


Figure 4-7 Possible direction for leading line (approx 318°N)

4.4.3 Arrival wind & waves from W / NW (run 15, 16, 21, 27 and 29)

In total 5 arrival runs were carried out for wind from 270°N and 300°N, including 1 run with an emergency. Table 4-6 summarizes the metocean conditions in these runs; the runs with an emergency are shaded. Though run 29 simulates an emergency with one of the tugs, the pilot continued the run to the berth normally. The run is therefore included here in the analysis of normal runs as well.

Table 4-6 Metocean conditions in the arrival runs for wind from 270°N and 300°N

Run nr	Current (in approach)		Wind		Sea waves		Swell waves	
	direction	speed	dir.	speed	dir.	sig. height	dir.	sig. height
	[°N to]	[m/s]	[°N fr]	[m/s]	[°N fr]	[m]	[°N fr]	[m]
15	225	1.0 / 0.5	270	14	270	0.5	220	1.7
16	225	0.5	270	14	270	0.5	220	1.7
21	225	0.5	300	12	300	0.5	220	1.7
27	225	0.5	270	12	270	0.5	220	1.7
29	180 / 225	0.5	270	12	270	0.5	220	1.7

Controllability

The controllability of the LNGC during the manoeuvre has been evaluated by visual inspection of the dataplots. Table 4-7 summarizes the results.

Table 4-7 Evaluation of controllability in the arrival runs for wind from 270°N and 300°N

Run nr	Rating instr.	Score ME power	Score safety index	Bow thruster		Tug 1			Tug 2			Tug 3			Tug 4			Free tug		Overall score	Run duration
				Max. rpm	Score	Connect. to	Max. force	Score	Connect. to	Max. force	Score	Connect. to	Max. force	Score	Connect. to	Max. force	Score	Connect. to	Score		
		[-]	[-]	[rpm]	[-]		[kN]	[-]		[kN]	[-]		[kN]	[-]		[kN]	[-]		[-]		[min]
15	+/-	+	0	0	++	CL bow	800	+	SB bow	700	+	SB aft	400	+	not connected			CL aft	0	+/-	40
16	+	0	+	300	+	CL bow	800	+	SB bow	0	++	SB aft	400	+	not connected			CL aft	0	+	48
21	+	0	0	0	++	CL bow	800	+	SB bow	700	+	SB aft	700	+	not connected			CL aft	-	+	57
27	+	+	0	300	+	CL bow	800	+	SB aft	700	0	SB bow	700	+	not connected			CL aft	0	+	61
29	+	0	+	300	--	CL bow	440	+	SB aft	700	+	SB bow	700	0	not connected			CL aft	+	+	42

The results show that the LNGC can be well controlled for these conditions. The opposing wind speed has the advantage that it is easier to reduce the speed of the vessel in the approach, while keeping sufficient control with engine and rudder. In most runs the use of main engine and rudder and the use of bow thruster and tugs is within the criteria for “just safe” or even “safe”. Only in run 21 the use of the stern tug is just over the criteria to line up the vessel parallel with the FSU for berthing, but this seems not strictly necessary to control the ship, as heading and lateral speed are rapidly corrected.

Used space

In run 15 the turn is started fairly quick after the vessel has entered the port, while the vessel is on the SB side of the entrance. The stern comes fairly close to the west cardinal buoy. This could easily have been avoided by starting the turn a bit later. Note also that this was probably the first manoeuvre of this pilot with this vessel. By doing more exercises during future training sessions the pilots will be more familiar with the ship and the manoeuvre and further optimise the strategy, so that they are prepared once the real operations start.

In run 21 the current sets the LNGC fairly far in SW direction and vessel enters the port relatively close to the main breakwater, but still with a safe clearance (approx 2B). All other runs are carried well within the available space with sufficient clearance to all relevant objects.

Discussion

From the tested directions wind from west appeared to be relatively straightforward. For these conditions the waves in the approach are lower so the behaviour of the tug in waves is not a limiting factor. The wind is therefore the main factor. The manoeuvre has been carried out at wind speeds up to 14 m/s (runs 15 and 16), which were both within the criteria for a safe run.

The check of the required tug capacity (see Section 2.4.3) showed that the four tugs of 70 tn BP used for the manoeuvre are more than sufficient to control the LNGC at a wind speed of 14 m/s. A wind speed limit of 14 m/s for north-westerly wind directions may therefore be possible. To keep the procedures initially simple, it is recommended to apply for arrival for wind from this direction the same 12 m/s limits as for the south-easterly and southerly directions. Based on experience gained in practice and/or other simulations (e.g. training sessions by the pilots) it may be possible to define a sector for which a higher wind speed limit can be adopted.

4.4.4 Departures (run 10, 18 and 24)

As the departure appeared to be fairly straightforward due to the geometry of the port, only one run was done for each of the three selected wind directions. All departure runs where carried out at a wind speed of 14 m/s.

Table 4-8 Metocean conditions in the departure runs

Run nr	Current (in approach)		Wind		Sea waves		Swell waves	
	direction	speed	dir.	speed	dir.	sig. height	dir.	sig. height
	[°N to]	[m/s]	[°N fr]	[m/s]	[°N fr]	[m]	[°N fr]	[m]
24	45	0.5	150	12	150	2.3	295	1.5
18	-	-	180	14	180	2.5	300	1.5
10	180	1.0 / 0.0	270	14	270	0.5	220	1.7

Controllability
The controllability of the LNGC during the departure manoeuvre has been evaluated by visual inspection of the dataplots. Table 4-9 summarizes the results.

Table 4-9 Evaluation of controllability in the departure runs

Run nr	Rating instr.	Score ME power	Score safety index	Bow thruster		Tug 1			Tug 2			Tug 3			Tug 4			Free tug		Overall score	Run duration
				Max. rpm	Score	Connect. to	Max. force	Score	Connect. to	Max. force	Score	Connect. to	Max. force	Score	Connect. to	Max. force	Score	Connect. to	Score		
		[-]	[-]	[rpm]	[-]		[kN]	[-]		[kN]	[-]		[kN]	[-]		[kN]	[-]		[-]		[min]
24	+/-	+	+	300	+	SB aft	390	+	SB bow	390	+	CL bow	510	+	not connected			CL aft	0	+/-	33
18	+	+	+	300	+	not connected			SB aft	400	+	CL aft	900	+	SB bow*	400	++	CL bow	0	+	19
10	+	-	-	0	++	not connected			SB aft	700	-	SB bow	700	-	CL aft	900	+	CL bow	-	+/-	19

It can be seen that in runs 18 and 24 all parameters are within the criteria. In run 10 the use of the two tugs in the side is at (nearly) maximum power for 3 – 4 minutes when pulling the LNGC from the berth. The free-sailing tug at the bow is also used at maximum power, but due to the small angle this does not contribute much to pulling the LNGC off the berth. It mainly starts the forward movement of the vessel. By using the tugs at the CL bow and CL aft as well to pull the vessel off, the use of the two side tugs could have been within the criteria as well. As discussed in Section 2.4.3 the four tugs should be sufficient to control the ship with sufficient margin for wind beam on. The use of engine and rudder is over the limit at the end of the run 10.

Used space
The trackplot for the three departure runs show that the manoeuvre can be carried out with sufficient clearance to all relevant objects.

Discussion
When the wind is from west (run 10) the LNGC is blown on the fenders. Once the mooring lines are gone all tugs are used to pull the LNGC off the FSU. The pilot increases the speed fairly rapidly to about 4 kn and let go the tugs. The speed is then increased at a slower pace, but it seems is was difficult to turn the ship away from the westerly wind and head for open sea. If the tugs would have remained connected and the speed a bit lower to make them effective, it should not be difficult to turn the vessel on the south-easterly course once it has reached the port entrance. The tugs must stay connected to keep the vessel under control until it is heading for open sea.

For wind from south (run 18) the lateral force on the LNGC are negligible. The tugs in the side (tug 2 and tug 4) pull initially with about 20 t, while the lines are disconnected. Once all clear, the bow and stern tug (free tug and tug 3) are used to pull the LNGC off the berth. Once the vessel reaches a speed of about 2.5 kn, the pilot orders all tugs to let go. As the instructor considers this an unsafe procedure for LNG carriers, he simulates an engine failure. The pilot reconnects the tug on the bow centre lead. It is recommended to keep the bow and stern tug connected until the vessel is clear of the Benghajsa Reef.

For wind from southeast (run 24) the wind is blowing the vessel off the berth, but the sheltering by the FSU reduces the wind loads. The tugs in the side (tug 1 and tug 2) must push to keep the LNGC in position until the mooring lines have been disconnected. Once all lines are gone, the vessel can leave the berth; the bow and stern tugs need to pull only for 1-2 minutes. When the distance is sufficiently large, the vessel can leave the port without tug assistance as the speed is still low when the 45 degree port turn must be made to head for open sea.

4.4.5 Emergencies (runs 25, 29, 30 and 31)

Four runs with an emergency were carried out to see whether these could be handled with the remaining tools and within the available space. For emergencies the normal criteria for evaluation of the runs do not apply anymore. The main criterion is whether a collision or grounding of the vessel can be avoided. In some cases a controlled grounding can even be a suitable solution. Table 4-10 shows the metocean conditions in the emergency runs.

Table 4-10 Metocean conditions in the emergency runs

Run nr	Current (in approach)		Wind		Sea waves		Swell waves	
	direction	speed	dir.	speed	dir.	sig. height	dir.	sig. height
	[°N to]	[m/s]	[°N fr]	[m/s]	[°N fr]	[m]	[°N fr]	[m]
25	225	0.5	150	12	150	2	295	1
30	225	0.5	150	12	150	2	295	1
31	225	0.25	180	12	180	2	300	1.5
29	180 / 225	0.5	270	12	270	0.5	220	1.7

Failure main engine (black-out)

In run 30 a blackout was simulated when the LNGC was close to the port entrance. The pilot dropped the port anchor to reduce the speed as he feared failure of the tow line of the stern tug in the waves if he would use the stern tug at high power to slow the ship down. He directed the tug from the starboard shoulder to the bow centre lead to assist in holding the ship in the wind.

The manoeuvre was carried out well within the available space in a very controlled way (see Figure 4-8). No large forces from the tugs were needed. In the position where the vessel is anchored it blocks access to the port, so it cannot stay there for long, but it is a suitable position to wait for additional tugs if required and coordinate with relevant authorities regarding the best strategy.

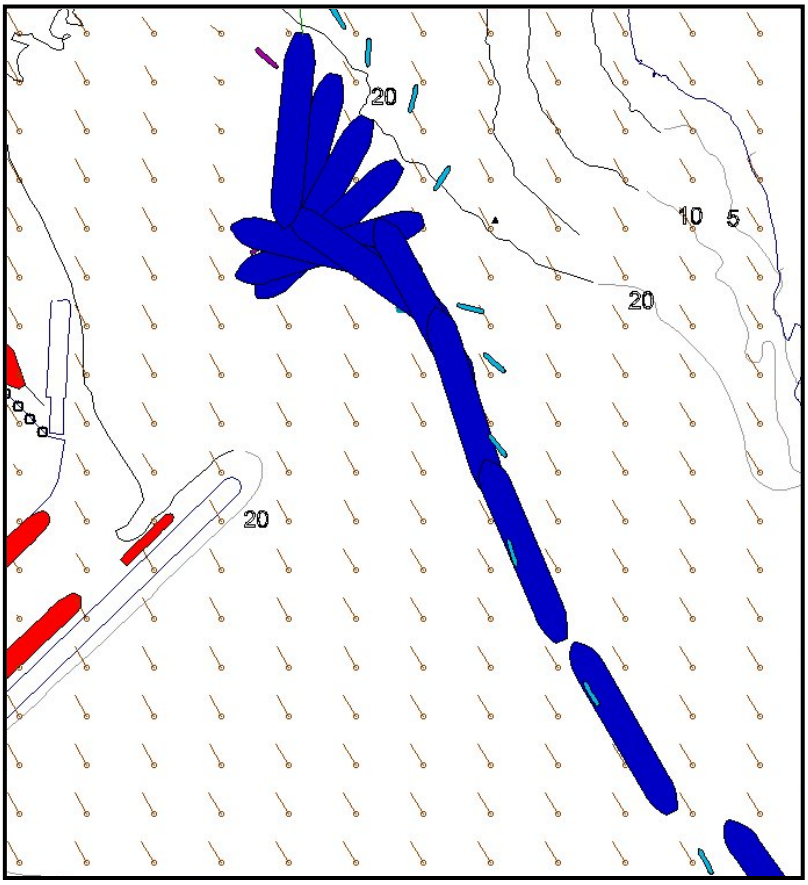


Figure 4-8 Sailed track when controlling the LNGC after a black-out when entering the port (run 30)

Failure stern tug

Two runs were carried in which a failure of the stern tug was simulated. In run 25 (wind 12 m/s from 150°N) the force of the stern tug was limited to 30 t, while in run 29 (wind 12 m/s from 270°N) a complete failure was simulated. In both runs the pilot continued the arrival manoeuvre to the berth. In run 25 the tug with reduced power was maintained on the stern. In run 29 the pilot redirected the tug from the centre lead bow to the stern and continued with the remaining three tugs and the bow thruster. Both runs were completed normally. In run 29 the use of the remaining tugs is even within the criteria for a safe run; the bow thruster is used at maximum power fairly long when turning the vessel, but when backing up and approaching the berth the use is within the criteria as well.

Failure bow tug

In run 31 a failure of the bow tug was simulated. This occurred just before entering the port. The pilot decided to abort the manoeuvre as he did not want to do the berthing with only 3 tugs and turned the vessel over port in a controlled way well within the available space near the Oil Tanking basin.

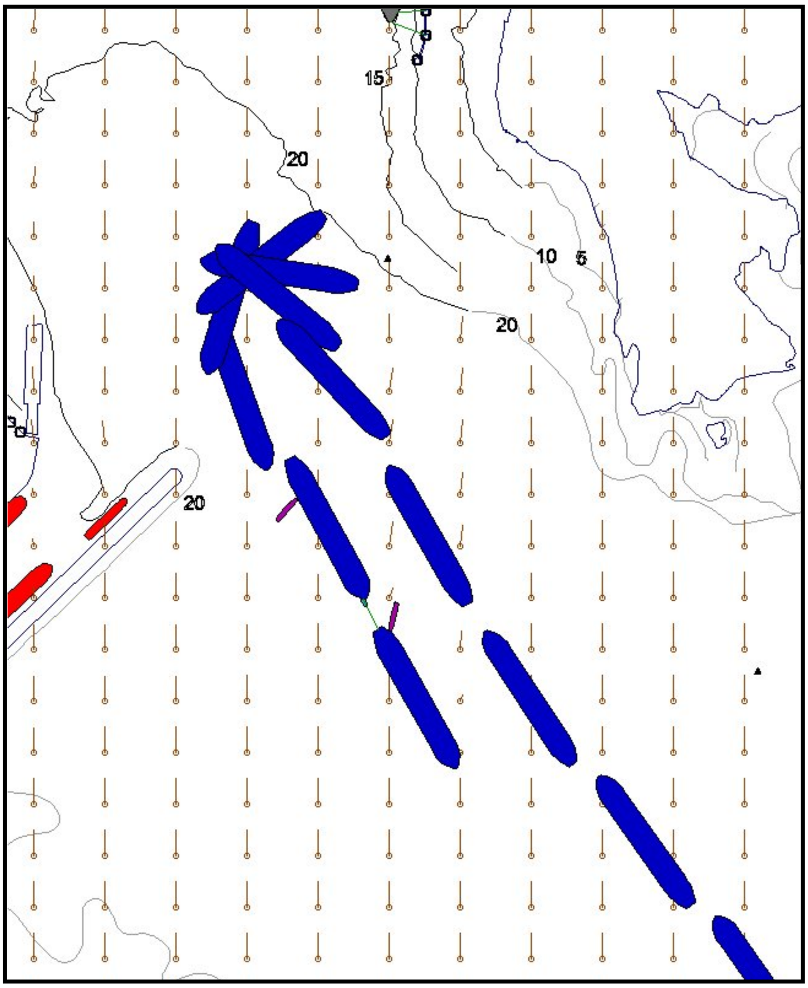


Figure 4-9 Sailed track when aborting the manoeuvre after failure of a tug (run 31)

Concluding remarks

From the few runs with an emergency it can be concluded that the port offers sufficient space to handle these emergencies in a controlled way. The port entrance is very wide, so that the LNGC can even turn there.

It is interesting to see the difference in response between the pilot in run 31, who is aborting the berthing with only 3 tugs available and the pilots in runs 25 and 29, who proceed to berth the LNGC. It is recommended that the pilots and the harbour master discuss the safest strategies in case of emergencies. Possible strategies may be:

- Aborting and returning to open sea (as in run 31)
- Rearranging the tugs at the vessel and proceeding to the berth (as in runs 25 and 29); e.g. in case of fairly mild conditions
- Control the LNGC on a suitable place in the port for a certain period while waiting for repair of the tug or until another tug has arrived.

The most suitable strategy can depend on the circumstances and the pilots may explore this further when doing training runs on the simulator to prepare for the first LNGC calling to the port.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Real-time manoeuvring simulations have been carried out on the simulator facilities of MMRTC in Malta to evaluate the metocean limits for operations with LNGC's for the new Delimara LNG terminal. Simulations were carried out for conditions that are expected to be the more critical directions for these operations. Based on the simulations that were carried out the following conclusions can be drawn:

1. Arrival manoeuvres with the LNGC can be safely carried out under the following conditions:
   - The wind speed is smaller than or equal to 12 m/s
   - The significant wave height in the approach to the port is smaller than or equal to H_s = 2 m
   - Four tugs with a bollard pull of 70 tons are available.

2. The cross-current of 0.5 m/s (1 kn) in the approaches caused no particular problem for the manoeuvre, though in the simulations the LNGC was set from the preferred track as some time was needed to adapt to the current.

3. For wind and waves from south-easterly directions (from NE to SW) the wave in approach is probably the governing factor. The skill and experience from the tug master to operate in high waves are a vital factor.

4. For wind from westerly directions a limit of 14 m/s may eventually be possible, as the wave height in the approach is lower for these directions due to sheltering by the land.

5. Departure manoeuvres can be carried out for wind speeds up to 14 m/s. Departures beyond this limit were not explored in the simulations.

6. Two tugs are required during the approach; four tugs are required during turning, backing up and berthing. The stern tug must be connected sufficiently far outside the port to allow effective use to reduce the speed of the LNGC during the approach.

5.2 Recommendations for nautical procedures

Based on the results of the simulations the following recommendations can be made:

1. To allow implementation of the above mentioned operational limits, actual information regarding wind, waves and current is indispensable. Installation of a wind meter and a wave / current station at a suitable location in the approach (e.g. a buoy or mounted on a pile) with continuous transmission of the measurements (e.g. every 10 minutes) is highly recommended. The measured wind and wave data can be used as an unambiguous reference to decide whether the manoeuvre can be safely carried out or not, while the current information allows a pilot to anticipate on the actual conditions in the approach.

2. Training of pilots and tug masters before the start of the manoeuvres with the LNGC is recommended. This training can also be used to optimise the strategy for the operations and standardize the procedures.

3. For the arrival manoeuvre the following strategy is recommended:
   Approach
   - Transit at minimum steering speed; this varies from ship to ship, but 6 kn is a typical value
   - Connect two tugs at the forward and aft centre leads
   - Once connected, use the stern tug to control the speed
   - The speed when passing the breakwater should not exceed 4 knots.

   Turning
   - Connect the third and fourth tug in the final part of the approach on the starboard side shoulder and quarter (if weather permits)
   - Once inside the harbour basin, stop the vessel in about 1.5 times the ships length and turn over port, away from the FSU (this gives lee to the tugs in the side and creates maximum manoeuvring space

   Berthing
   - Manoeuvre the vessel astern to a position west of the FSU;
   - Control lateral motion when crabbing towards and berthing alongside the FSU with the tugs (tugs in the side for pushing, tugs on centre lead fore and aft for pulling)
   - Correct longitudinal position and speed using the main engine
   - Use the tugs to keep the LNGC in position when securing the mooring lines

4. For the departure manoeuvre the following strategy is recommended:
   De-berthing
   - Use the tugs to control the LNGC when disconnecting the mooring lines
   - Keep the spring lines clear from the fenders between LNGC and FSU
   - Use the tugs to pull the LNGC of the berth once mooring lines are gone

   Manoeuvring and turning
   - Once the vessel is clear from the FSU, use the main engine to increase the speed to about 4 kn
   - Disconnect the two tugs on SB shoulder and quarter, keep tugs at forward and aft centre lead connected
   - Turn the vessel to port around the west cardinal buoy, if necessary with assistance the tugs

   Leaving port
   - Increase the speed to about 6 kn
   - Keep the tugs on bow and aft centre lead connected until the vessel is well clear of the Benghajsa Reef (safety measure for emergencies).

5. It is recommended to carry out the operations involving LNGCs with two pilots on board: one drives the vessel, the other monitors the manoeuvre.

6. During the berthing pilots should have information regarding the lateral speed of the LNGC towards the FSU, either from a PPU or from a berthing aid system installed on board of the FSU.

7. No other (sea-going) traffic must be allowed in the vicinity of the LNGC during manoeuvring.

8. It is understood that the pilots use the ship's ECDIS for manoeuvring. The accuracy of this system is unknown for the pilot. He has to rely that relevant parameters are correctly defined and that the position of the ship shown on the ECDIS is correct. The pilots may consider using a Portable Pilot Unit (PPU) system for manoeuvres involving LNGCs (and the largest container vessels). An additional advantage is that such a system can be further enhanced to show e.g. measured waves and currents or by inserting reference tracks that are used to display track and course deviations.

9. In practice it may be challenging to connect the ASD tug bow to bow at a speed of about 6 kn in waves. Instead of an ASD tug a tractor drive may be preferred for use at the bow.

10. To avoid peak loads in the tow line, it can be beneficial to have some load on the line. Dedicated winches (e.g. rendering/recovery winch) or an adequate stretcher may also be useful to reduce peak loads.

5.3 Recommendations for future training simulations

During the simulations a few items had to be set or modified at the start of the run (e.g. current speed and direction, factor on wind speed or wave height). Experience showed that due to this manual set-up of the run, the conditions are not always as desired and some correction is required. For future training simulations it is recommended to define some more fixed scenarios (requiring none or little manual setting). This allows e.g. to adjust the ship's heading at the start of the run to the current included in the scenario, so that the pilot needs little time to adapt the course to the conditions. It is recommended to make the following changes to the database:

1. Prepare SW-going and NE-going current fields that have a zero speed inside the port (so that no manual changes are required during the run);
2. Prepare arrival scenarios for the above current fields with a corrected heading of the LNGC so that the coarse over the ground is in the correct direction;
3. Prepare wave fields that have a significant wave height of about Hs = 2 – 2.5 m (operational limit for the tug);
4. Prepare wind fields of 12 m/s (operational limit for LNGC);
5. Modify the scenarios to use the above wind and wave conditions.

6 REFERENCES

[1] MARIN/ARCADIS, 2015. Nautical and risk studies for the Delimara LNG Terminal in Marsaxlokk Port, Malta; Item 1: Wave climate study. Report No. 27689-1-MSCN-rev.1. Prepared for Enemalta
[2] MARIN/ARCADIS, 2015. Nautical and risk studies for the Delimara LNG Terminal in Marsaxlokk Port, Malta; Item 2: Wave penetration study. Report No. 27689-2-MSCN-rev.1. Prepared for Enemalta
[3] SIGTTO, 1997. LNG Ship Data Book. Second edition, October 1997.
[4] SIGTTO, 2007. Prediction of Wind Loads on Large Liquefied Gas Carriers.
[5] Svasek, 2013. Current and Wave Study Marsaxlokk Bay; Enemalta - LNG jetty at Delimara. Final report 1720/U13238/B/BvL. Prepared for: iAS Architects & Structural Engineers

APPENDIX A: CONVENTIONS AND DEFINITIONS

CONVENTIONS AND DEFINITIONS

A.1. Units

In principle all parameters and variables have units according to the international SI conventions. These units are used in presentation of results in e.g. dataplots. Mariners with operational experience are, however, used to express distance, speed and force using different non-SI units such as:

Maritime term	Quantity	Name of unit	Symbol for unit	Value in SI units
mile	distance	nautical mile	M	1852 m
knot	speed	knot	kn	0.51444 m/s
ton	force	ton force		9.81 kN

As this report is meant to be read by people with a maritime background, the above units are often used in the description and discussion of results.

A.2. Notations

The following notations are used in this report:

- . decimal point. Thus 1.5 means one and half.
- , digit grouping symbol. Thus 12,000,000 means 12 million.
- E for the scientific notation with the exponent of 10. Thus 1.2E-3 means 1.2 x 10^{-3} = 0.0012

A.3. Directions

For the directions of wind, waves, currents and headings the nautical/meteorological convention is used in which directions are given clockwise relative to North:

- Wind/wave directions are **coming from** (90°N = wind from east)
- Current direction are **going to** (90°N = current to east)
- Heading direction are **going to** (90°N = sailing to east)

A.4. Coordinate systems

In the chapters that describe the input and results of the simulations, it is relevant to note that three coordinate systems are used as reference for various parameters. This is illustrated in Figure A.1.

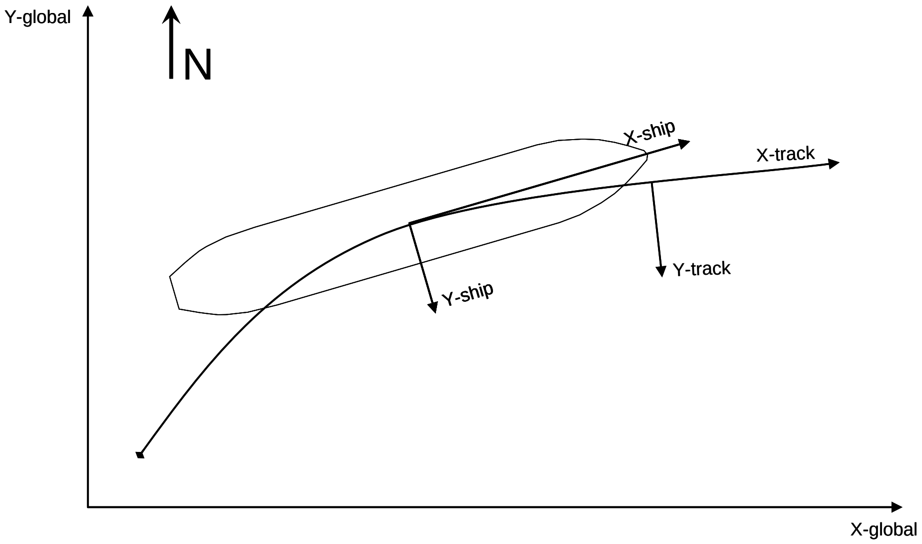


Figure A.1 Coordinate systems used in the manoeuvring simulations

Ship-fixed coordinate system

For the forces on and motions of the vessel, a local, ship-fixed coordinate system is used with the origin in the centre of the vessel. For manoeuvring studies a different ship-fixed coordinate system is usually applied than in some other fields. In this ship-fixed system for manoeuvring applications, the X-axis of the local coordinate system points towards the bow, the Y-axis to **starboard** side. Angles, directions and moments are defined positive in clockwise direction relative to the x-axis. Figure A.2 illustrates the definition of the directions (of e.g. wind) in this ship-fixed coordinate system.

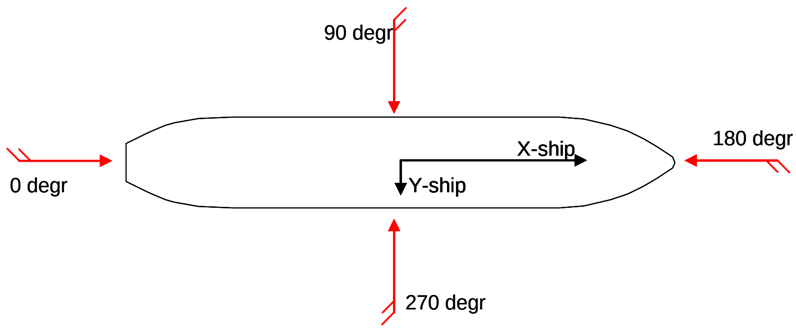


Figure A.2 Ship-fixed coordinate system and definition of directions in this system

Track coordinate system

A coordinate system linked to the reference track is used in the simulations to define a number of parameters such as the track deviation and the drift angle. The orientation of this coordinate system is similar to the ship-fixed system: the X-axis is along the track, the Y-axis is perpendicular to the track to the right/starboard side (Figure A.1). A positive track deviation means that the vessel is right of the required track; a positive drift angle is a clockwise rotation relative to the track.

Global coordinate system

A global coordinate system is used for the layout of the area, the definition flow and wave fields and the calculated positions of the ship.

APPENDIX B: NOTES FROM THE MARIN INSTRUCTOR

The remarks of the MARIN instructor made during the simulations are summarised in the table below. The following abbreviations are used in this description:

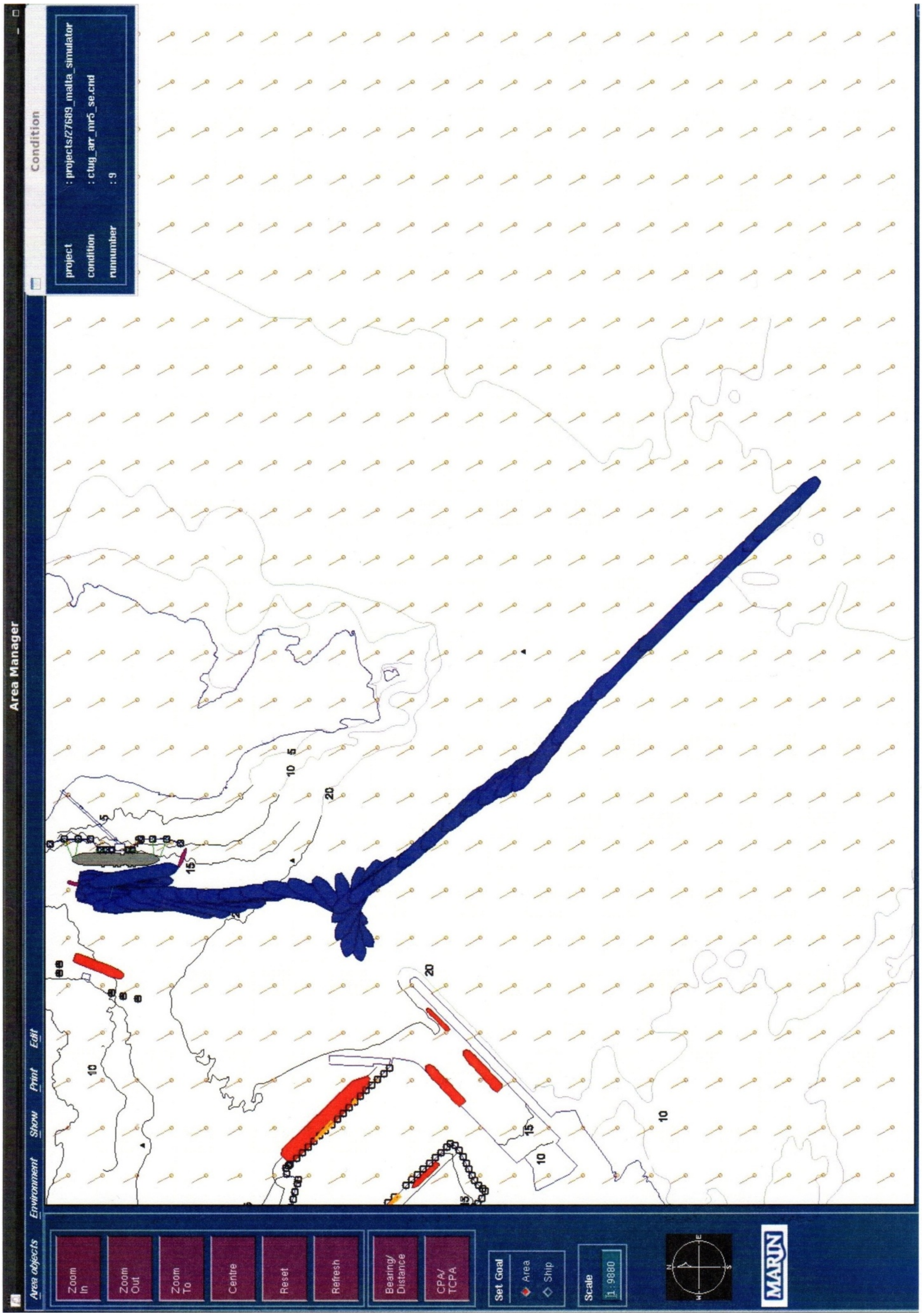
CPA	closest point of approach	SB	starboard side
ME	main engine	SOG	speed over the ground
PS	port side	STW	speed through the water
ROT	rate of turn	TC	turning circle

Run	Scenario and conditions	Remarks	Rating
Monday 24 November 2014			
9	ctug_arr_mr5_se Wind: 10 m/s to 150°N Current: no current Sea: Hs = 2.3 m from 150°N Swell: Hs = 1m from 295°N	Familiarization run. Connected 4 tugs, 2 centre lead and 2 SB shoulder/quarter. SB shoulder tug man operated. Turned over PS in harbour entrance. Backed up towards FSU. Controlled manoeuvre. *Pilot comment: turned vessel in sheltered position for tugs.*	+
10	ctug_dep_mr5_w Wind: 14m/s from 270°N Current: changed to 0 kt to 90°N Sea: Hs = 0.5 m from 270°N Swell: Hs = 1.7 m from 220°N	Departure. Four tugs connected. Fwd tug man operated. Manoeuvred parallel away from FSU. All tugs disconnected in harbour basin. Headway in harbour entrance 6 knots.	+
11	ctug_arr_mr5_se Wind: 10 m/s from 150°N Current: 1 kt to 225°N Sea: Hs = 2.3 m from 150°N Swell: Hs = 1.0 m from 295°N	Arrival. Four tugs connected. Fwd tug man operated, line length 95m later shortened to 70 m. SOG at harbour entrance 5.8 kts. Turned vessel over SB and drifted rapidly to NW. ME full ahead to stop sternway. Fwd tugs at full power. CPA mooring buoy 50m. Dropped SB anchor at 180 m from FSU. Controlled side step towards FSU. *Pilot comment: Stern tug connected too late with high speed as result.*	-
12	ctug_arr_mr5_se Wind: 14 m/s from 150°N Current: 2 kt to 180°N Sea: Hs = 3.2 m from 150°N Swell: Hs = 1.5 m from 295°N	Arrival. Four tugs connected. Fwd tug man operated, line length 56m. SOG at breakwater head 5.0 kts. Turned vessel over SB and relative close (±3B) to FSU. Fwd tug line parted. Pivot point close to the bow. Fender impact 0.2 kts. *Pilot comment: feasible manoeuvre.*	+/-
13	ctug_arr_mr5_s Wind: 10m/s from 180°N Current: 1 kt to 45°N → 0 kt Sea: Hs = 2.0 m from 180°N Swell: Hs = 1.5 m from 300°N	Arrival. Four tugs connected. Stern tug man operated, line length 56m. SOG at breakwater head 3.0 knots. Turn over PS, stern close (<1B) to W cardinal buoy. Stern tug line parted (2 times) in turn. Berthing impact 0.7 kts. *Note: analysis shows that sea and swell were reduced to indicated values (from 3.2 resp. 1.5 m) after 4 min.*	+/-

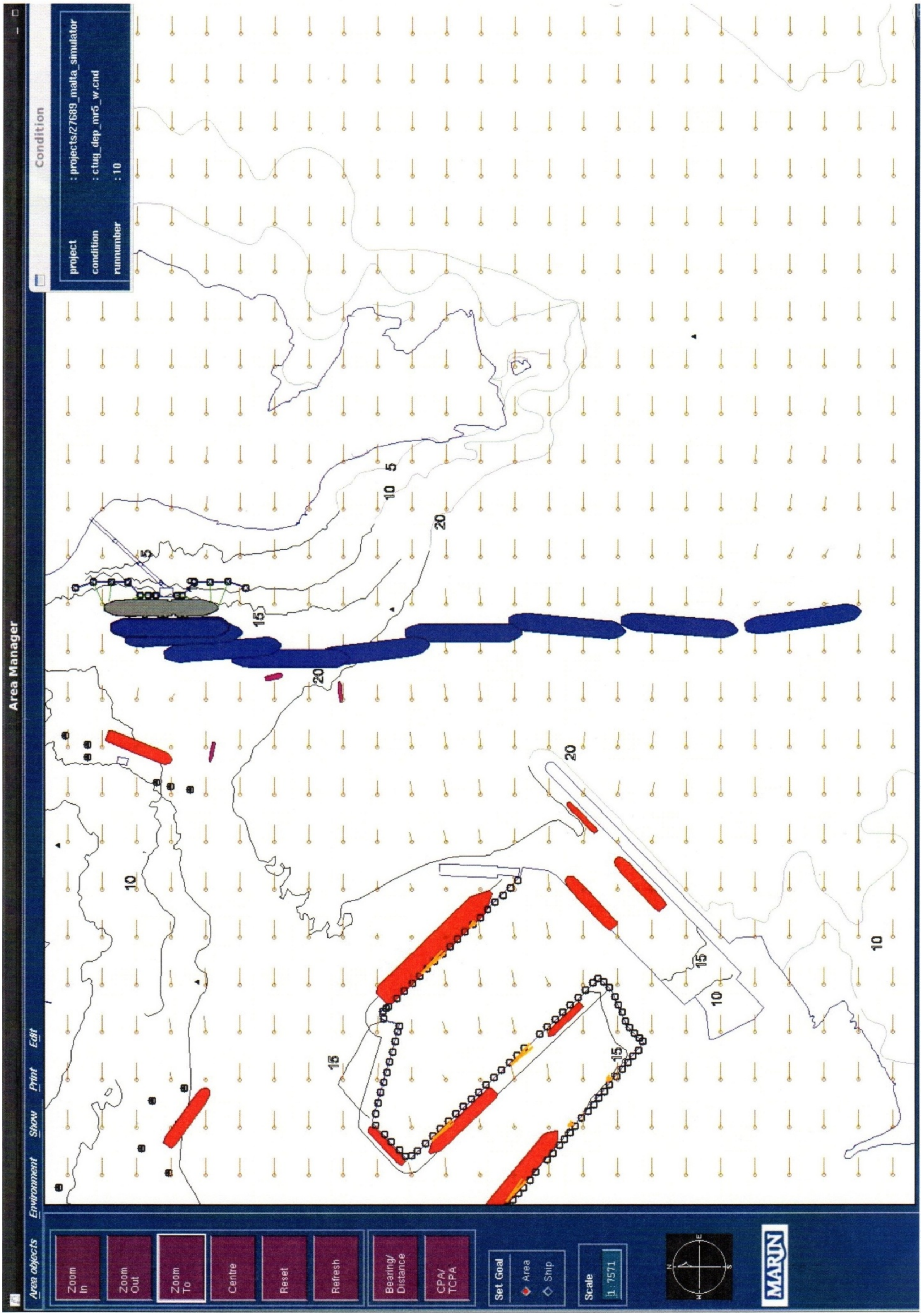
Run	Scenario and conditions	Remarks	Rating
Tuesday 25 November 2014			
15	ctug_arr_mr5_w Wind: 14 m/s from 270°N Current: 2 kt/1 kt to 225°N Sea: Hs = 0.5 m from 270°N Swell: Hs = 1.7 m from 220°N	Arrival. Four tugs connected. Fwd tug (VS). Stern tug (ASD) manned. SB drift in final approach when current reduces. SOG at breakwater head 3.0 knots. Stern close (±1B) to W cardinal buoy. Turn through port. Impact on fenders 0.7 knots. Note: difference in reading Doppler log and GPS radar vector.	+/-
16	Ctug_arr_mr5_w Wind: 14 m/s from 270°N Current: 1 kt to 225°N Sea: Hs = 0.5 m from 270°N Swell: Hs = 1.7 m from 220°N	Arrival. Four tugs connected. Fwd tug (VS). Stern tug (ASD) manned. SOG at breakwater head 2.6 knots. Turn through port ROT up to 20°/min. Back-up speed <1 knot. Instable lateral speed reading. *Pilot comment: I could have held the vessel in final berthing phase. Feasible manoeuvre.*	+
17	Ctug_arr_mr5_s Wind: 12 m/s from 180°N Current: 1 kt to 45°N Sea: Hs = 2.5 m from 180°N Swell: Hs = 1.2 m from 300°N	Arrival. Four tugs connected. Fwd tug (ASD) manned, line parted. Stern tug (VS). SOG at breakwater head 6.8 knots. All available resources used to stop the vessel. Turn through port. Controlled back up and final berthing. *Pilot comment: high speed at breakwater head can be avoided when run starts at larger distance from breakwater head.*	+/-
18	Ctug_dep_mr5_s Wind: 14 m/s from 180°N Current: no current Sea: Hs = 2.5 m from 180°N Swell: Hs = 1.5 m from 300°N	Departure. Four tugs connected. Fwd tug (ASD) manned. 12.15 engine failure. Pilot reconnected fwd (manned tug). Better to keep fwd and aft tug connected until vessel is clear of Benghajsa shoals.	+
19	Ctug_arr_mr5_se Wind: 12 m/s from 150°N Current: 1 kt to 180, then 225°N Sea: Hs = 2.0 m from 150°N Swell: Hs = 1.0 m from 295°N	Arrival. Four tugs connected. Fwd tug (ASD) manned by Pilot J. Approach speed 5.3 knots no tugs used. At breakwater head SOG 4.6 knots. Stern tug full to stop vessel. Turn over port pivot point midships. Back up speed 1.3 knot. *Pilot comment: feasible manoeuvre*	+
20	Ctug_arr_mr5_s Wind: 12 m/s from 180°N Current: 1 kt to 180°N Sea: Hs = 2.0 m from 180°N Swell: Hs = 1.5 m from 300°N	Arrival. Four (C) tugs connected. Smooth approach with a speed of 6.0 knots. At breakwater head SOG 3.7 knots. Vessel turned over port in harbour entrance. Stern (unnecessary) very close (10m) to buoy. Back up speed <1 knot. Controlled berthing.	+
Wednesday 26 November 2014			
21	Ctug_arr_mr5_w Wind: 12m/sec from 300°N Current: 1kt to 225°N Sea: Hs = 0.5 m from 270°N Swell: Hs = 1.7m from 220°N	Arrival. Four tugs connected. Fwd tug (VS). Stern tug (ASD) manned. Stern tug line length 85m. Approach shows drift to port due to the current. SOG at breakwater head 3.0 knots. Distance to 15m depth 50m. Turn over port, pivot point midships. Back up speed < 1.5 knot. Smooth line up and berthing. *Pilot comment: In approach no tug used, turn, back up and berth no problem.*	+
22	Ctug_arr_mr5_s Wind: 12 m/s from 180 °N Current: 1 kt to 45°N Sea: Hs = 2.0 m from 180°N Swell: Hs = 1.5 m from 300°N	Arrival. Four tugs connected. Stern tug (ASD) manned, Fwd tug (VS). Collided S cardinal buoy. SOG at breakwater head 4 knots. Turn over port. Back up SOG <1.5 knots. *Pilot comment: collision with buoy is easily to avoid.*	+/-
24	Ctug_dep_mr5_se Wind: 12 m/s from 150°N Current: 1 kt to 45°N Sea: Hs = 2.3 m from 150°N Swell: Hs = 1.5 m from 295°N	Departure. Four tugs connected. Fwd tug (ASD) manned. Tow line length 100m. Disconnected side tugs inside harbour basin. Disconnected centre tugs clear of reef, first fwd. Feasible for escorting but on the limit for disconnecting. SOG 5 knots. *Tug master comment: feasible.*	+/-
25	Ctug_arr_mr5_se Wind: 12 m/s from 150°N Current: 1 kt to 225°N Sea: Hs = 2.0 m from 150°N Swell: Hs = 1.0 m from 295°N	Arrival. Four tugs connected. Fwd tug (ASD) manned. Approach SOG 6.5 knots. SOG at breakwater head 5.8 knots. At 12.15 Stern tug failure, max force reduced to 30 tons. Turn over port. SOG back up 2.1 knots. Smooth manoeuvre despite tug failure. *Pilot comment: I preferred to turn the vessel earlier.*	+

Run	Scenario and conditions	Remarks	Rating
Thursday 27 November 2014			
27	ctug_arr_mr5_w Wind: 12 m/s from 270°N Current: 1 kt to 225°N Sea: Hs = 0.5 m from 270°N Swell: Hs = 1.7 m from 220°N	Arrival. Four tugs connected. Fwd tug (VS). Stern tug (ASD) manned. Stern tug line length 85m. Stern tug line snapped at 50m length. SOG at breakwater head 1.5 knot. Turn over port. Pivot point in midships. SOG back-up <1.5 knot. Controlled berthing. *Pilot comment: To our standard the manoeuvre is going slow.*	+
28	ctug_arr_mr5_s Wind: 12 m/s from 180 °N Current: 1 kt/0.5 kt to 180, then 225°N Sea: Hs = 2.0 m from 180 °N Swell: Hs = 1.5 m from 300 °N	Arrival. Four tugs connected. Fwd tug (VS). Stern tug (ASD) manned. Stern tug line length 80m. Smooth approach. SOG at breakwater head 4.0 knots. Turn over port ROT up to 18°/min. Pivot point close to the bow. Stern tug just clear of W cardinal buoy. *Pilot comment: feasible condition.*	+
29	ctug_arr_mr5_w Wind: 12 m/s from 270°N Current: 1 kt to 225°N Sea: Hs = 0.5 m from 270°N Swell: Hs = 1.7 m from 220°N	Arrival. Four tugs connected. Fwd tug (VS). Stern tug (ASD) manned. Stern tug line length 80m. SOG at breakwater head 3.6 knots. At 12.15 stern tug failure. Redirected centre lead forward tug to centre lead aft. (10 min). Turn over port. Stern 1B distance from buoy. *Pilot comment: Three tugs can keep the vessel in safe position.*	+
30	ctug_arr_mr5_se Wind: 12 m/s from 150°N Current: 1 kt to 180, then 225°N Sea: Hs = 2.0 m from 150°N Swell: Hs = 1.0 m from 295 °N	Arrival. Four tugs connected. Fwd tug (VS). Stern tug (ASD) manned. Stern tug line length 80m. 12.13 Black out. Dropped port anchor. Vessel stopped in 10 min and travelled about 1 ships length. Vessel turned over port, heaved in 1 shackle and redirected SB shoulder tug to bow. Vessel under control. *Pilot comment: I hope this doesn't happen. Dropped anchor as precaution in case stern tug line parts in waves.*	+
31	ctug_arr_mr5_s Wind: 12m/s from 180 °N Current: 0.5 kt to 225°N Sea: Hs = 2.0 m from 180°N Swell: Hs = 1.5 m from 300°N	Arrival. Four tugs connected. Fwd tug (VS). Stern tug (ASD) manned. Stern tug line length 80m. At 200m from breakwater head SOG 5.6 knots fwd tug failure. Vessel turned over port and departed. *Pilot comment: no berthing in this condition with 3 tugs.*	+
33	ctug_arr_mr5_s_ctug Wind: 14 m/s from 180°N Current: 1 kt to 225°N Sea: Hs = 2.5 m from 180°N Swell: Hs = 1.5 m from 300°N	Arrival. Four (C) tugs connected. In approach there is a strong tendency to turn to port, corrected with hard over rudder and sometimes full ahead. Turn over port ROT up to 12°/min. Pivot point close to bow. Back up SOG 2.0 knot. Smooth berthing.	+

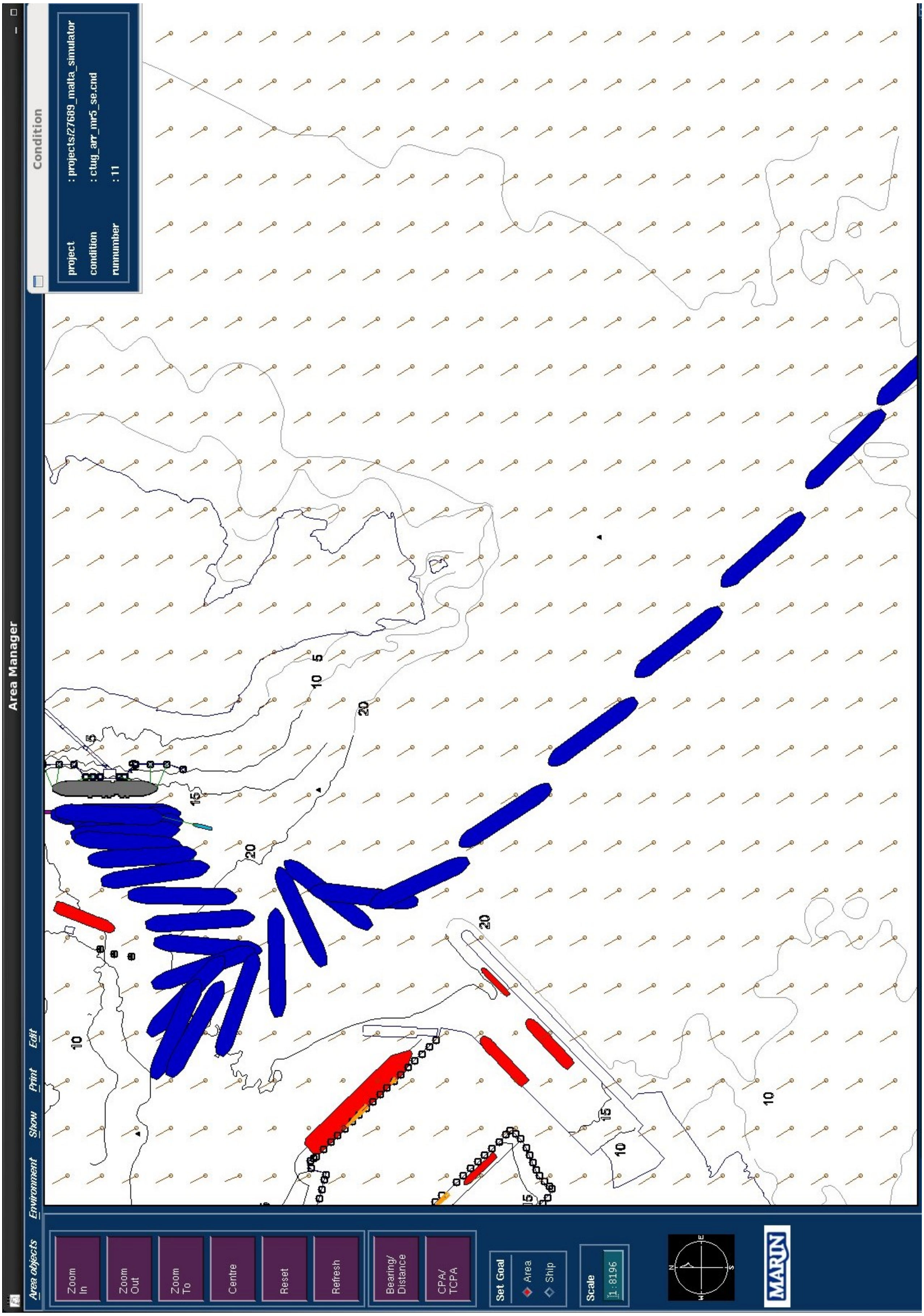
APPENDIX C: TRACKPLOTS OF SAILED RUNS



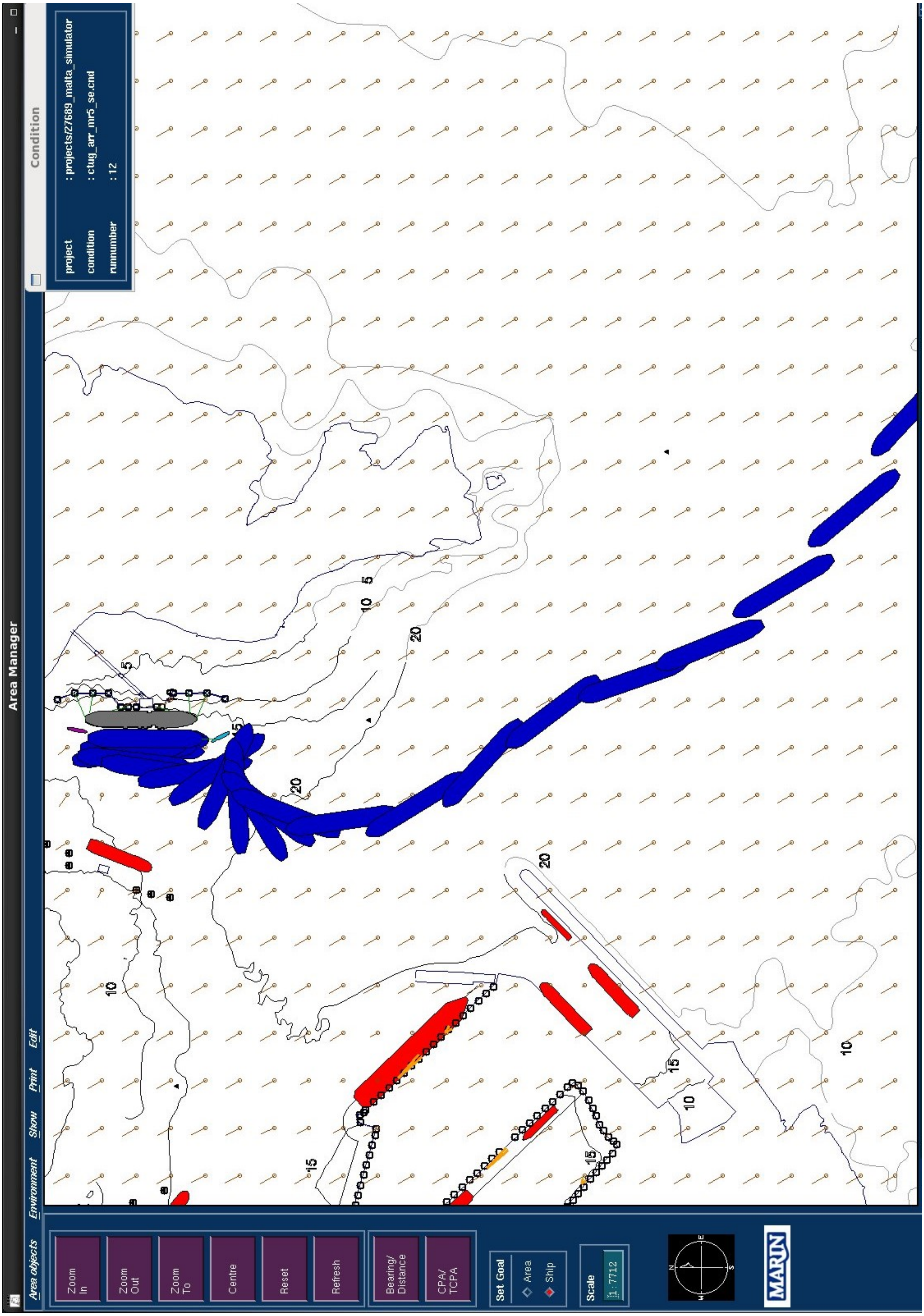
Plot C-1 Trackplot of run 9



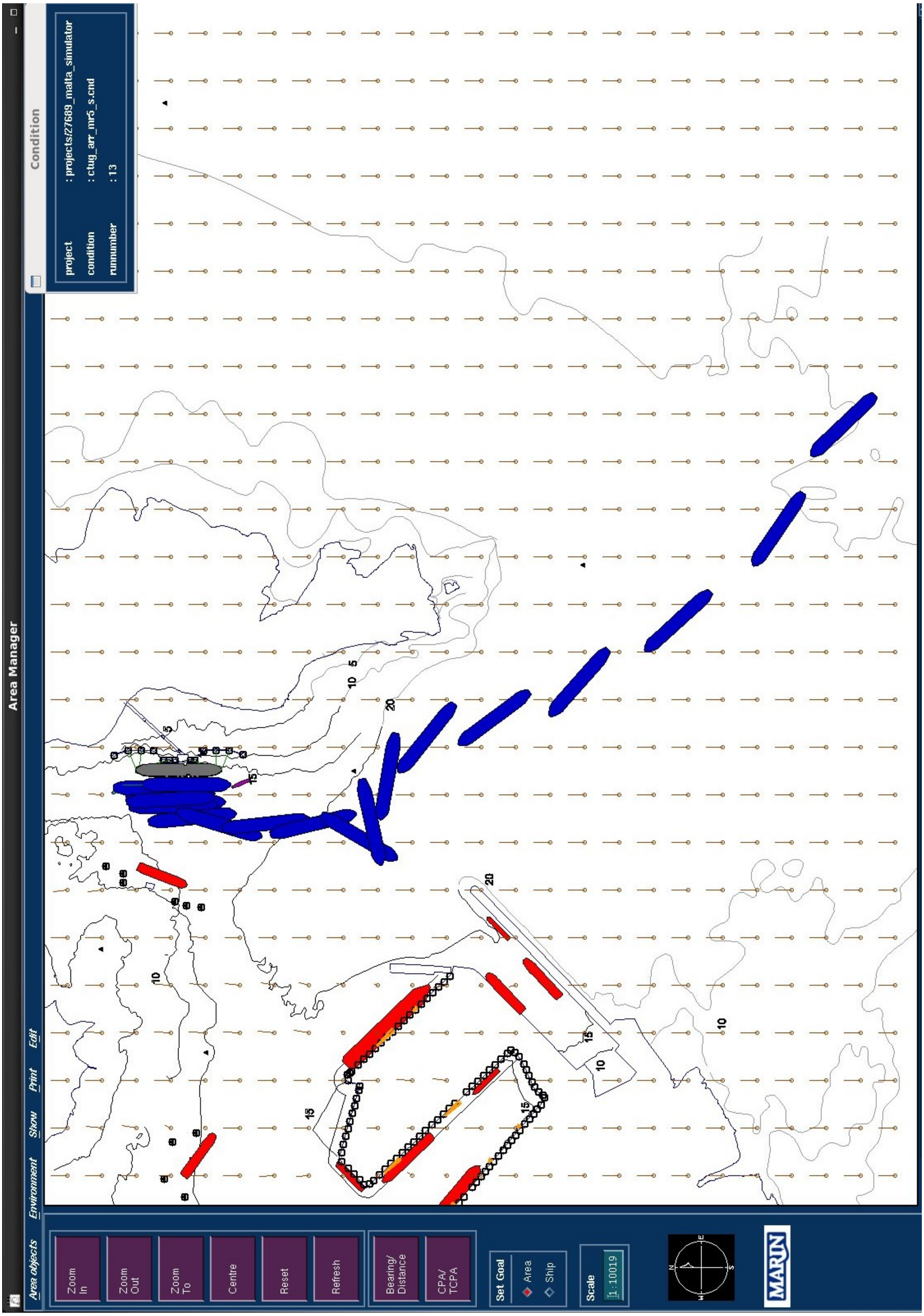
Plot C-2 Trackplot of run 10



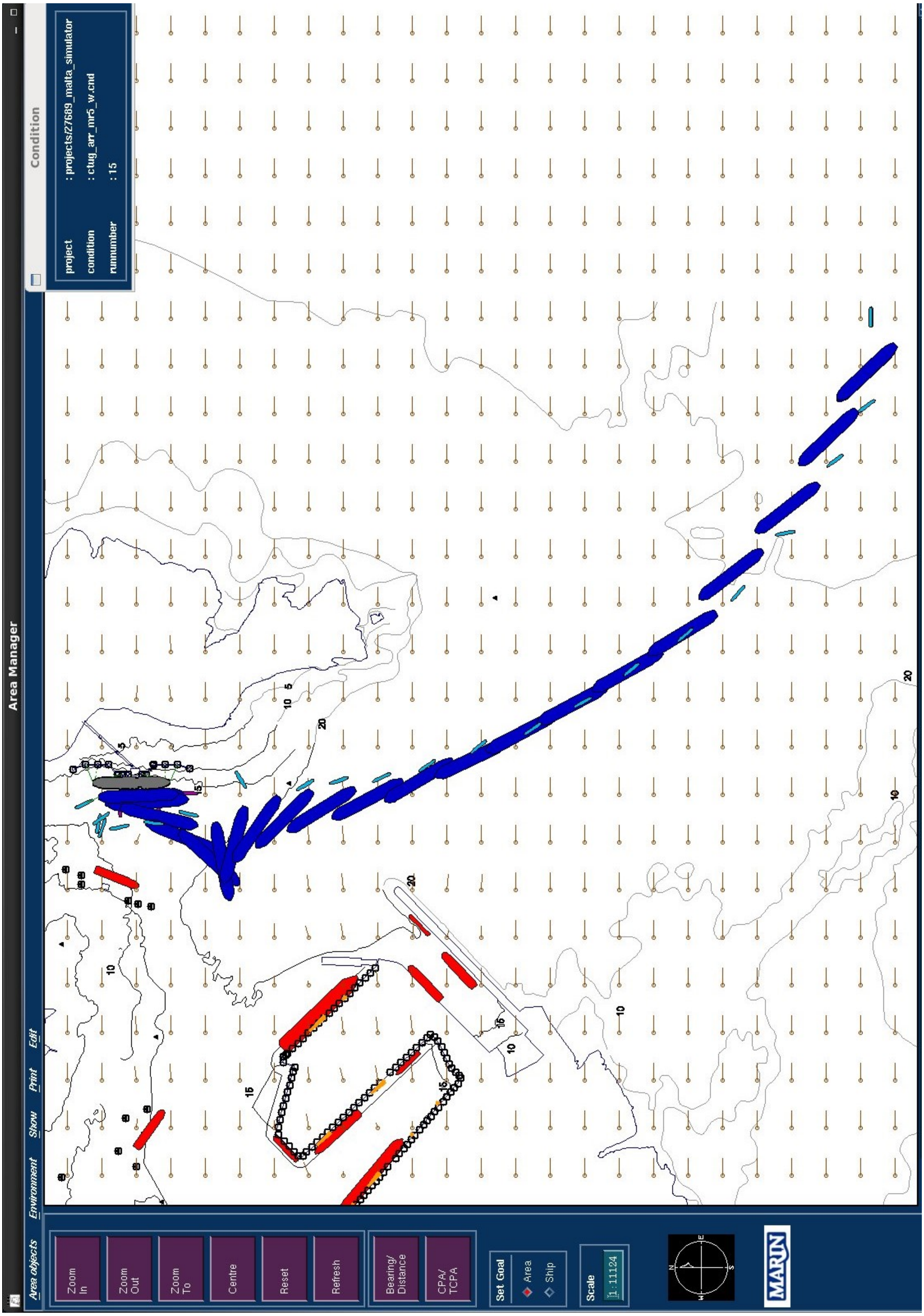
Plot C-3 Trackplot of run 11



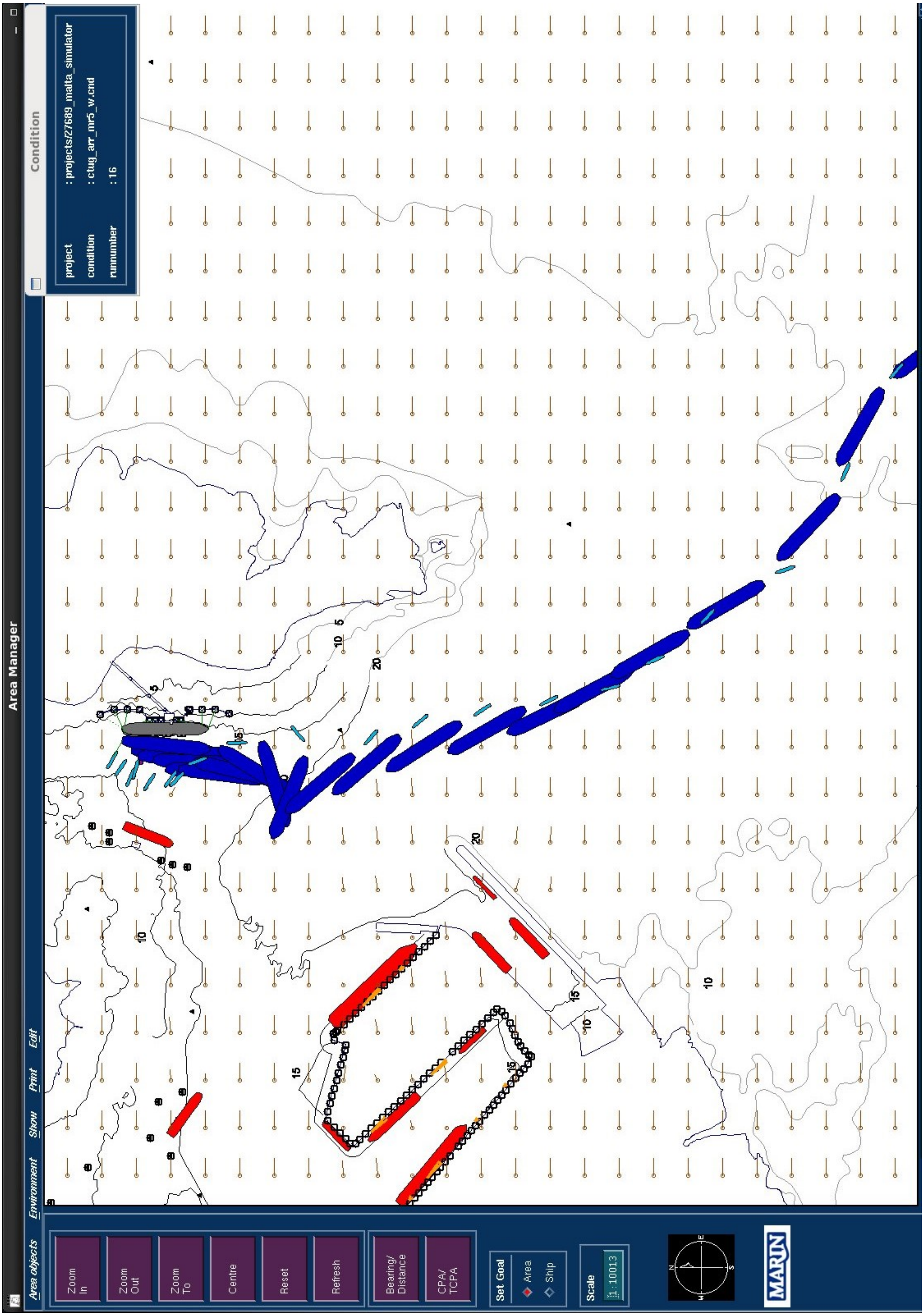
Plot C-4 Trackplot of run 12



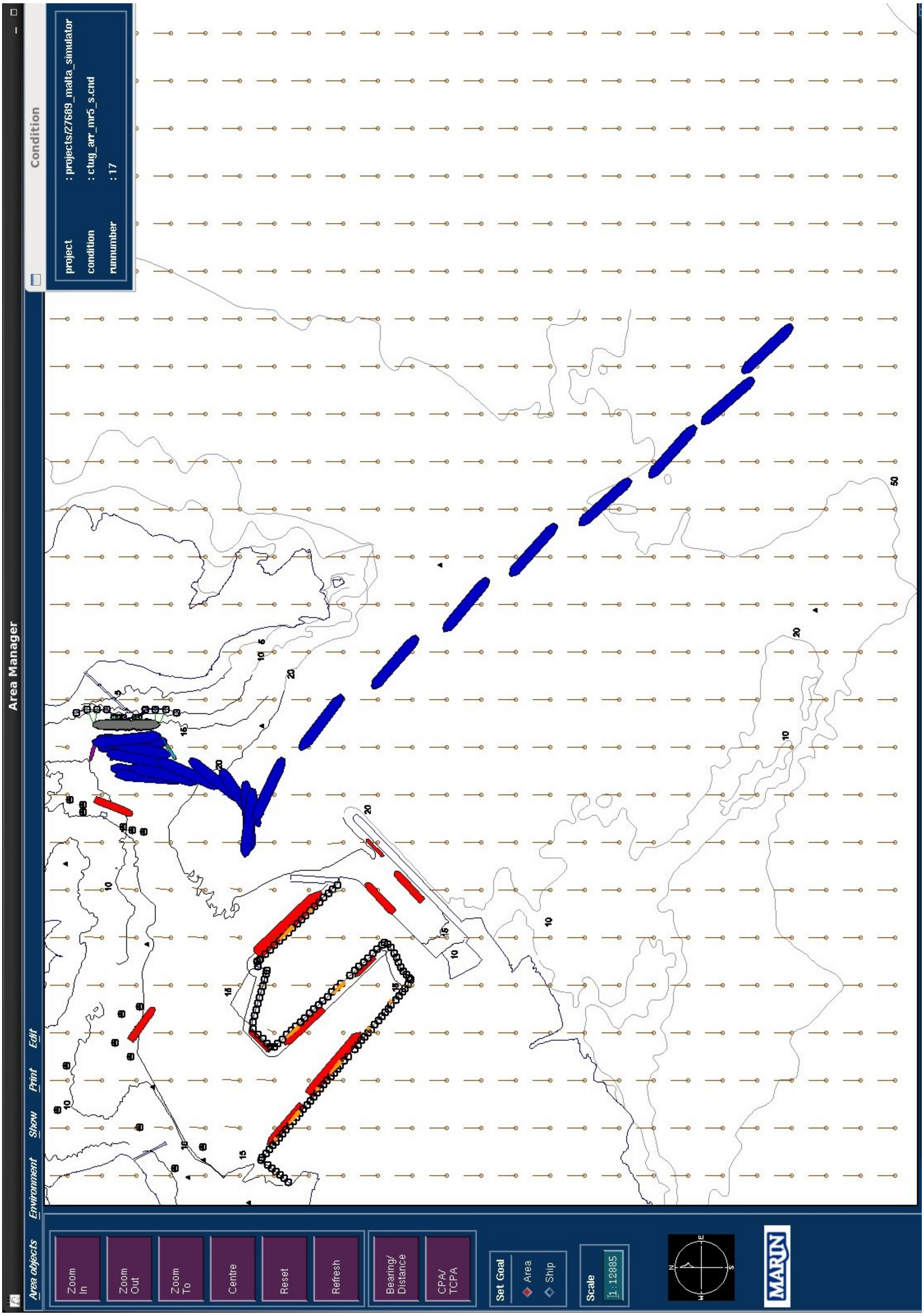
Plot C-5 Trackplot of run 13



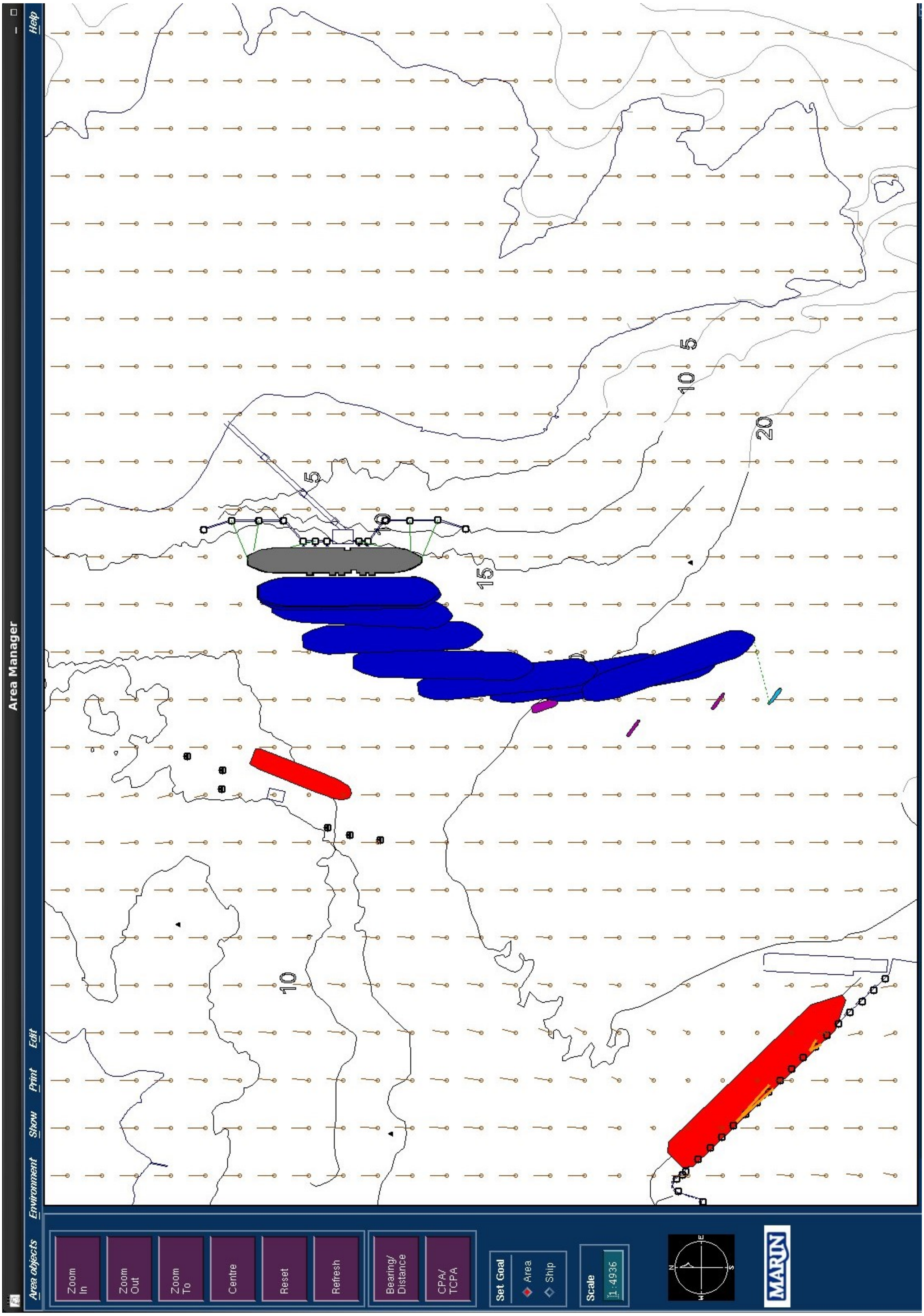
Plot C-6 Trackplot of run 15



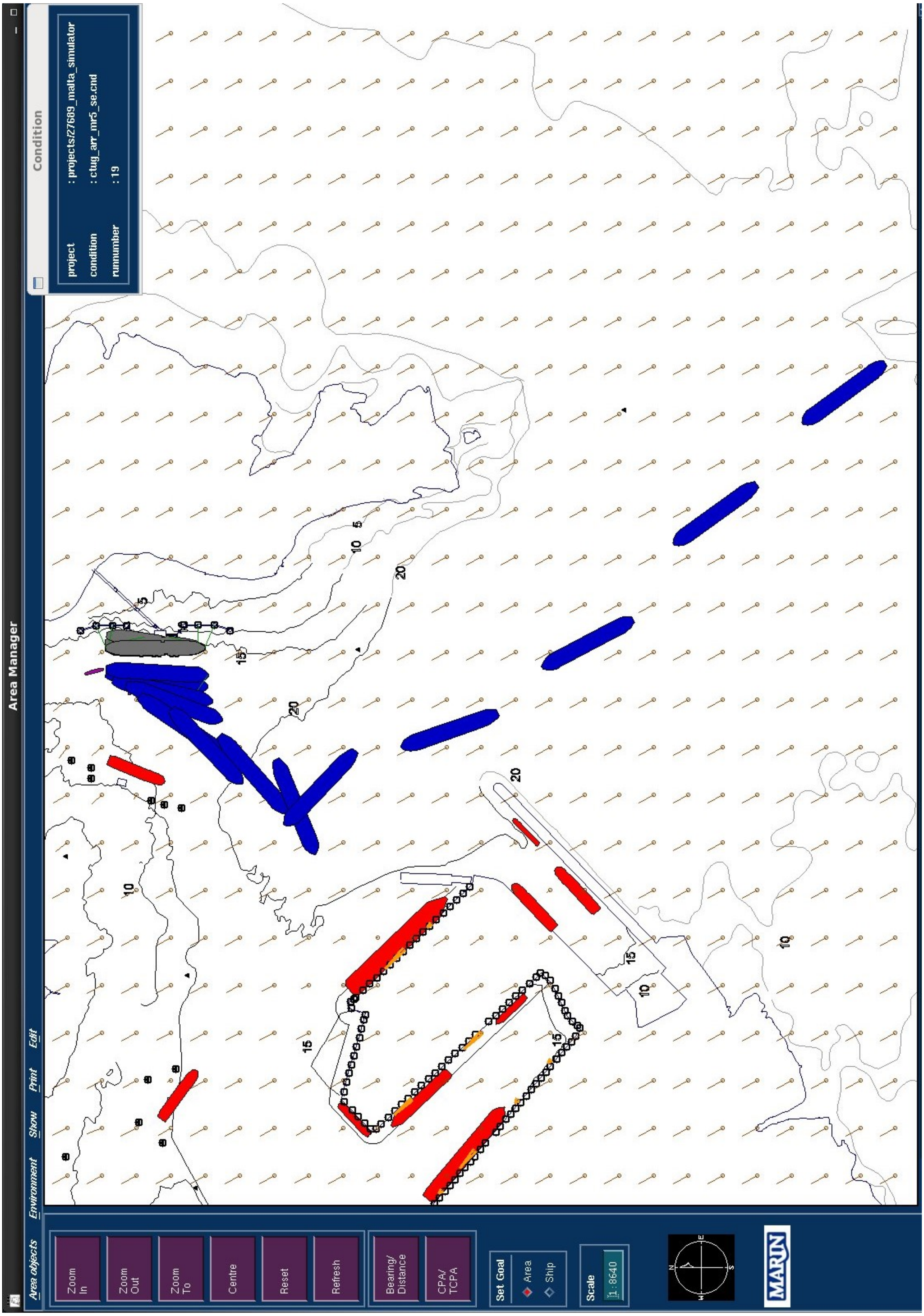
Plot C-7 Trackplot of run 16



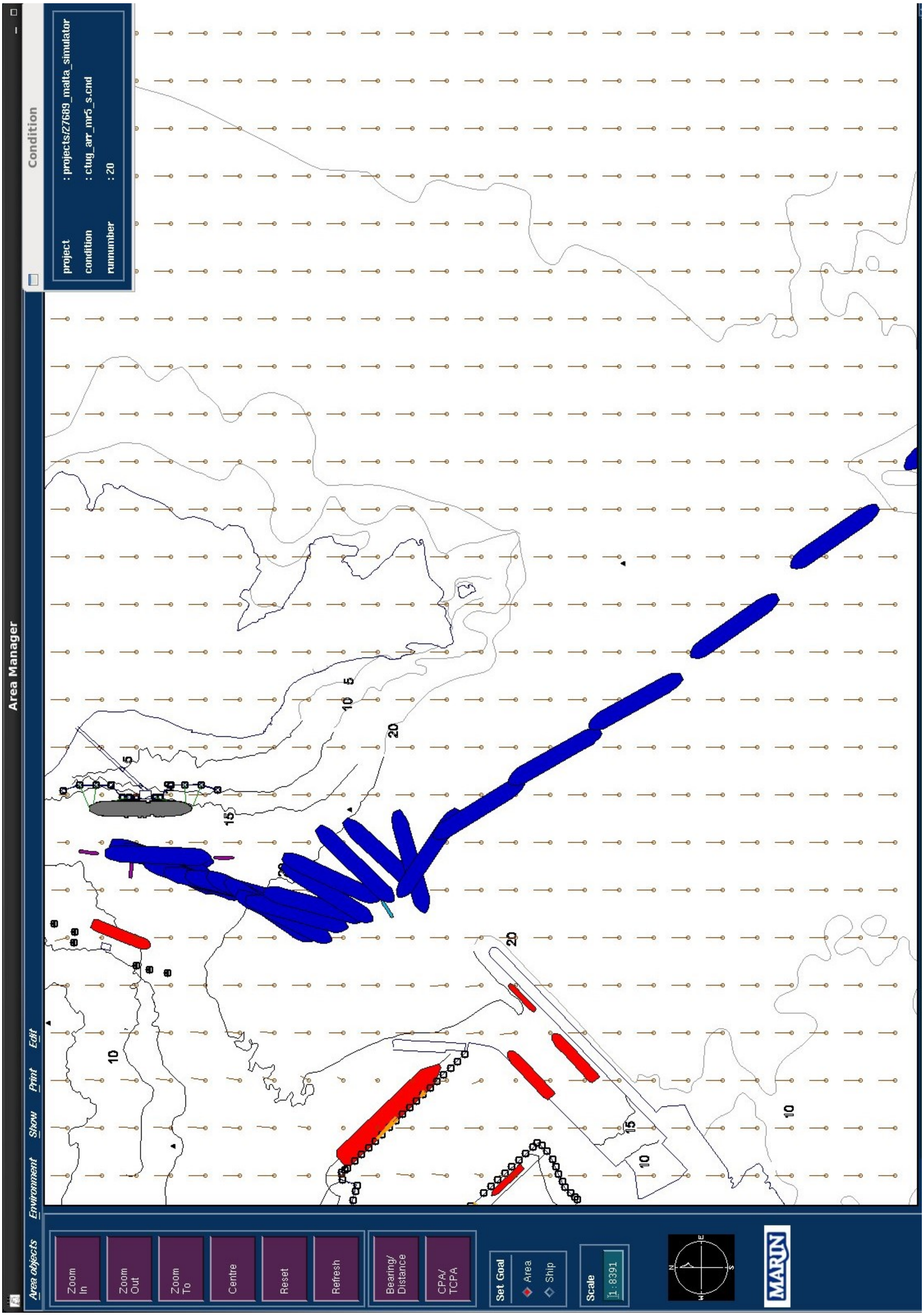
Plot C-8 Trackplot of run 17



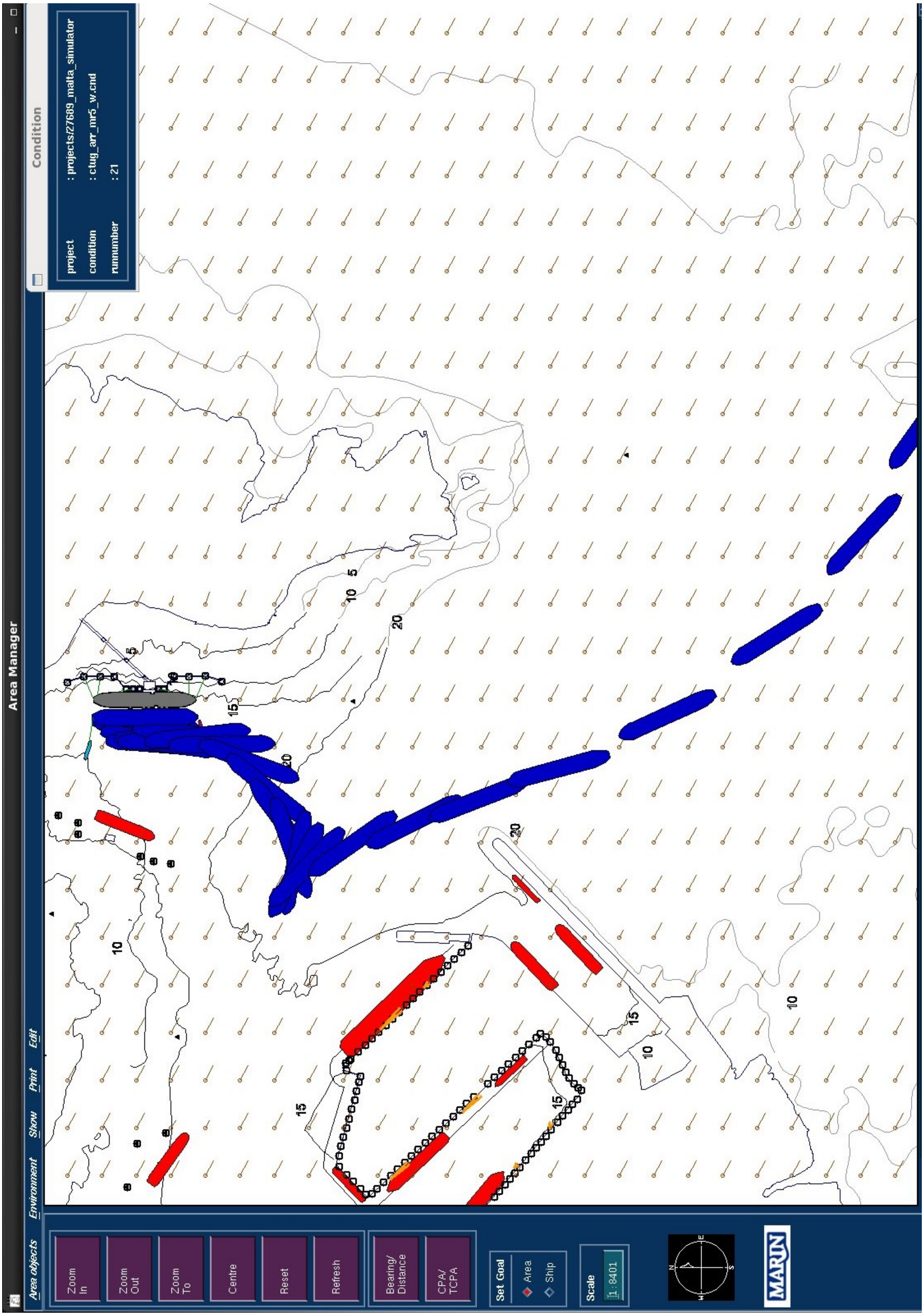
Plot C-9 Trackplot of run 18



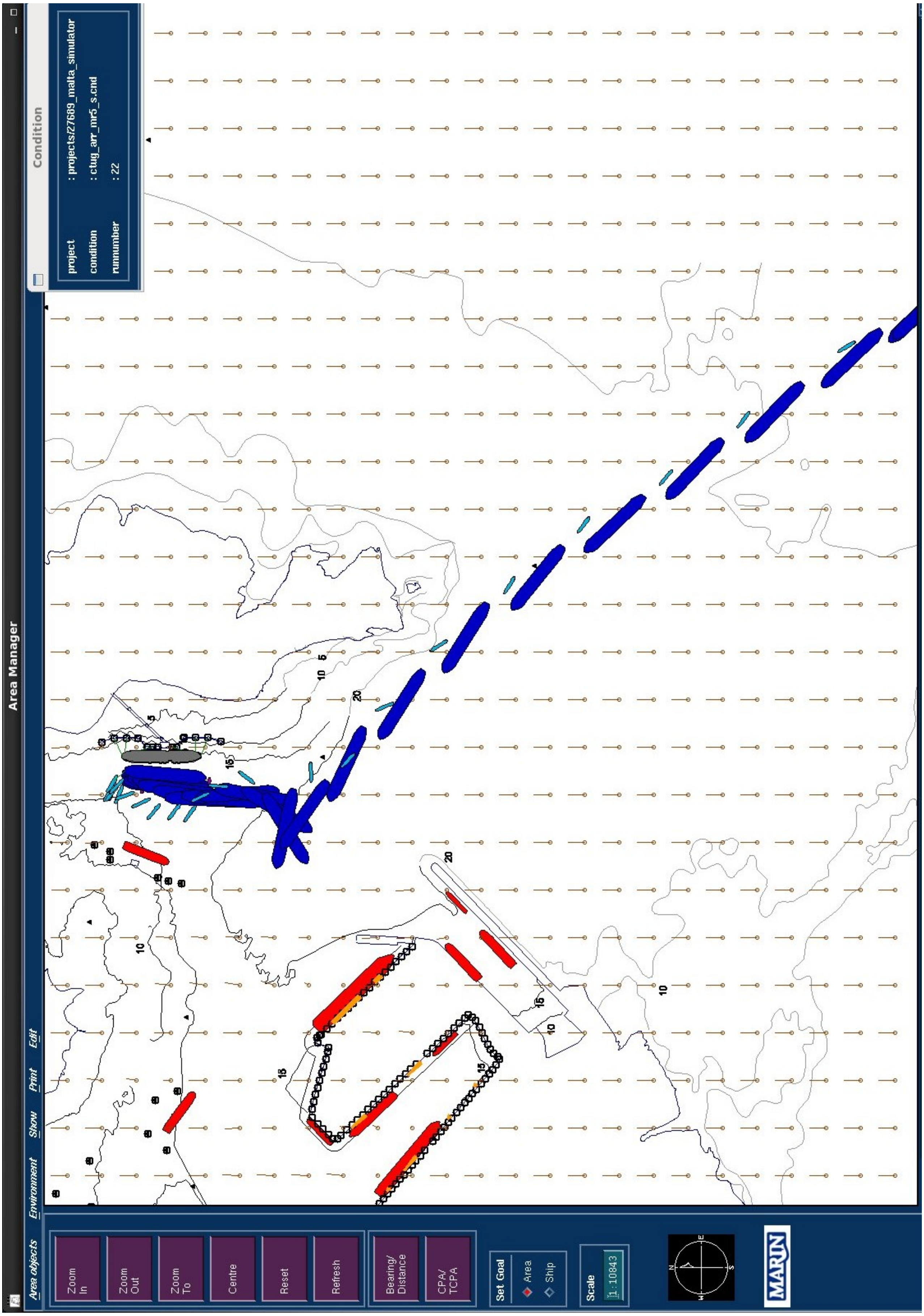
Plot C-10 Trackplot of run 19



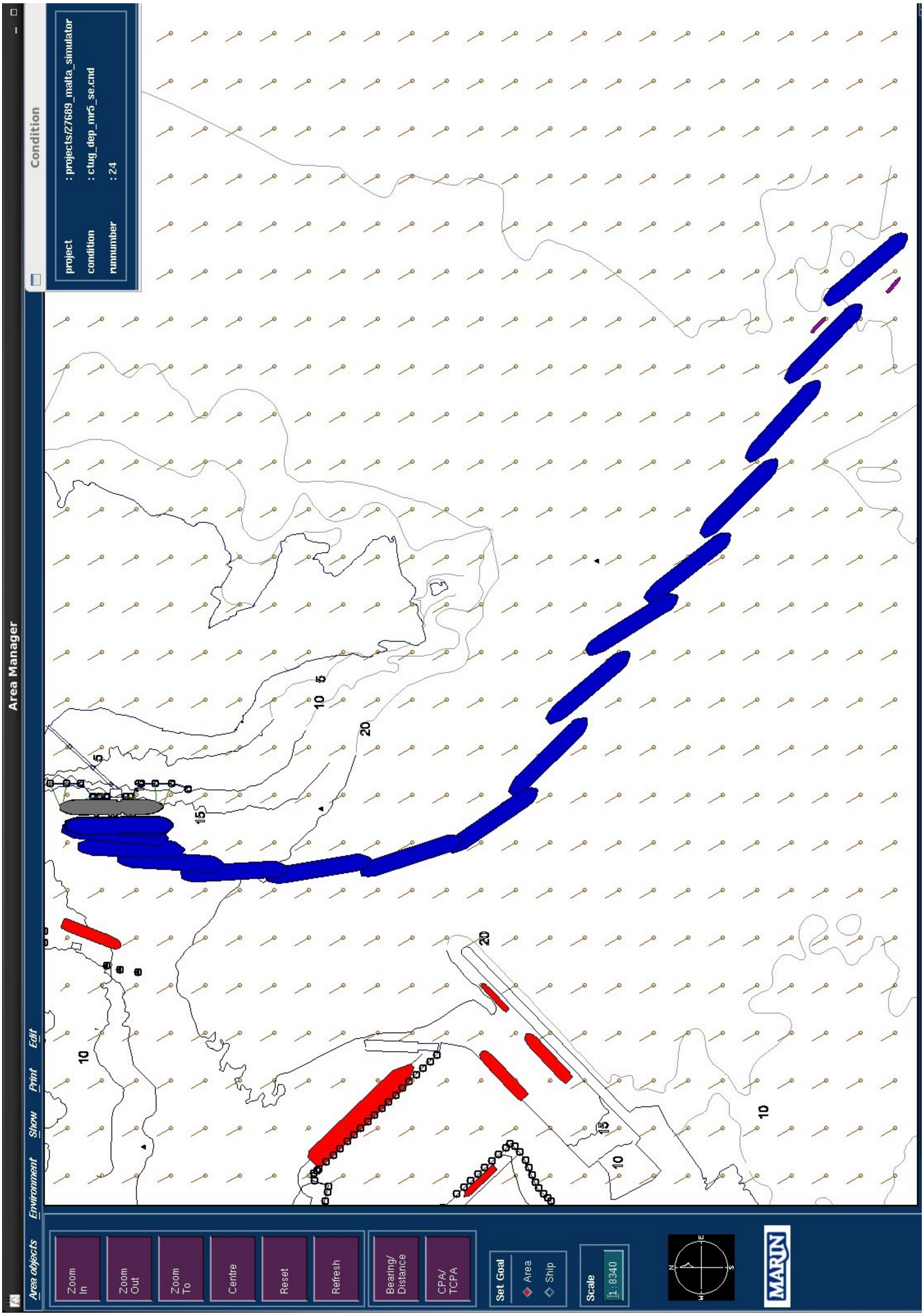
Plot C-11 Trackplot of run 20



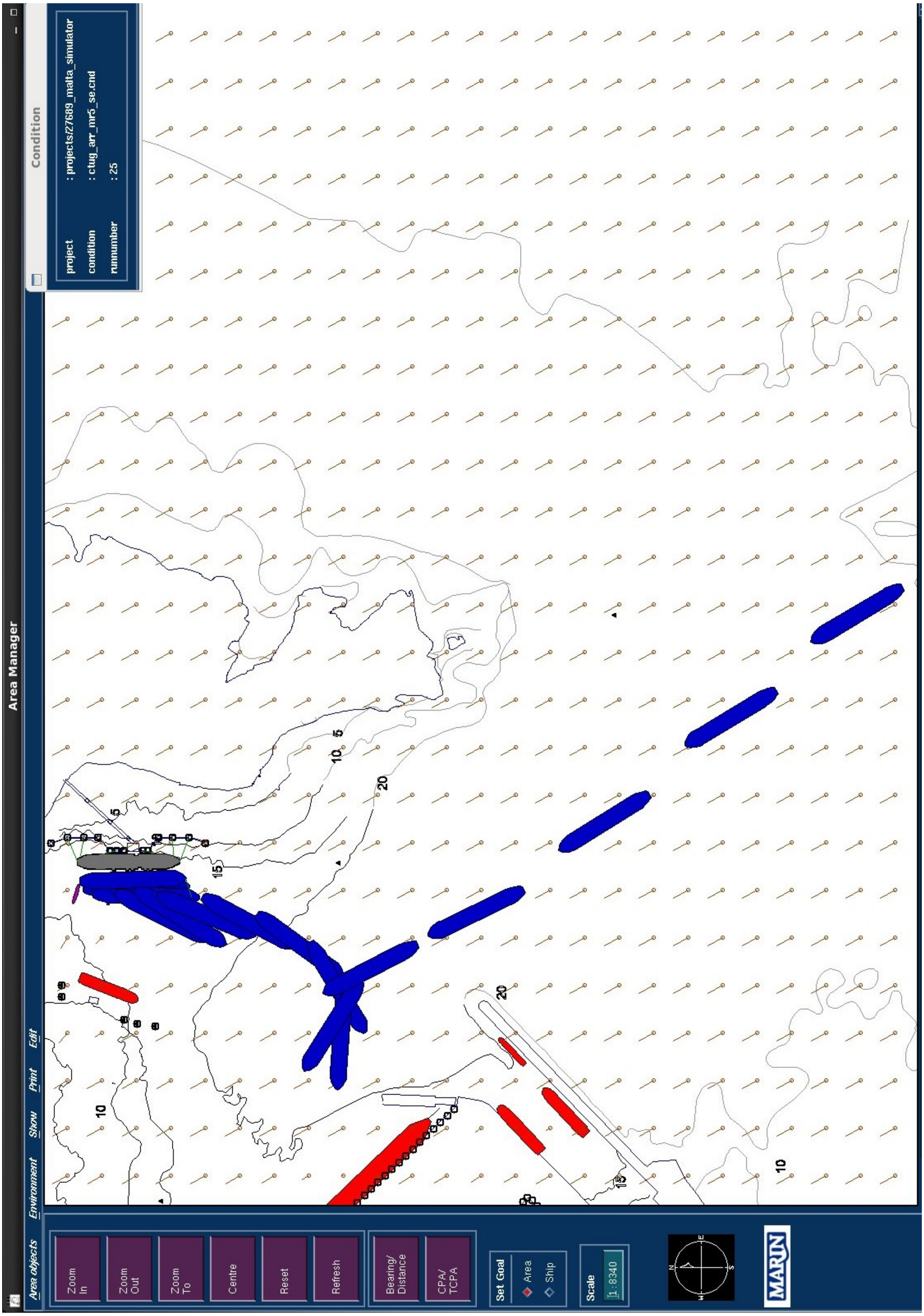
Plot C-12 Trackplot of run 21



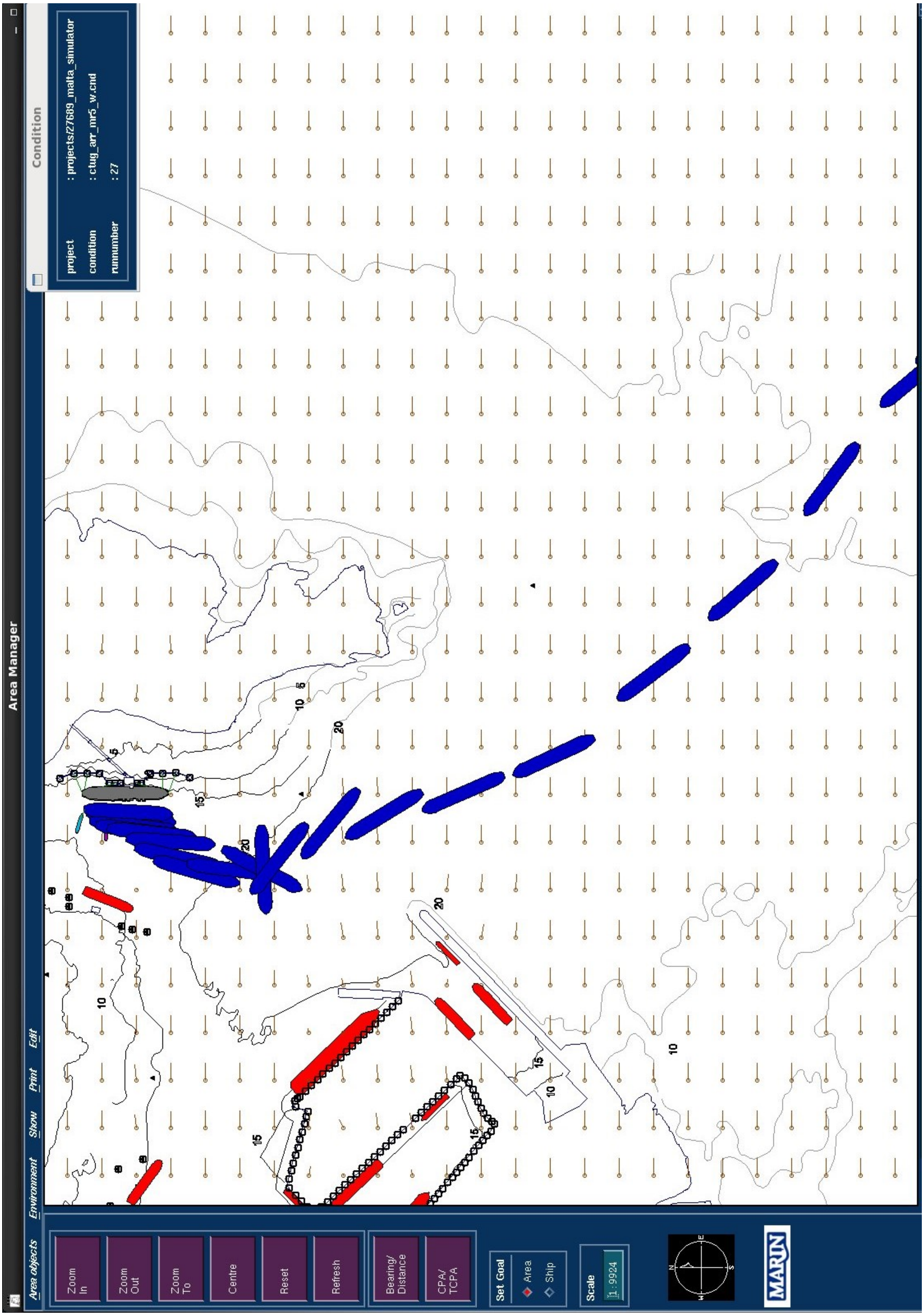
Plot C-13 Trackplot of run 22



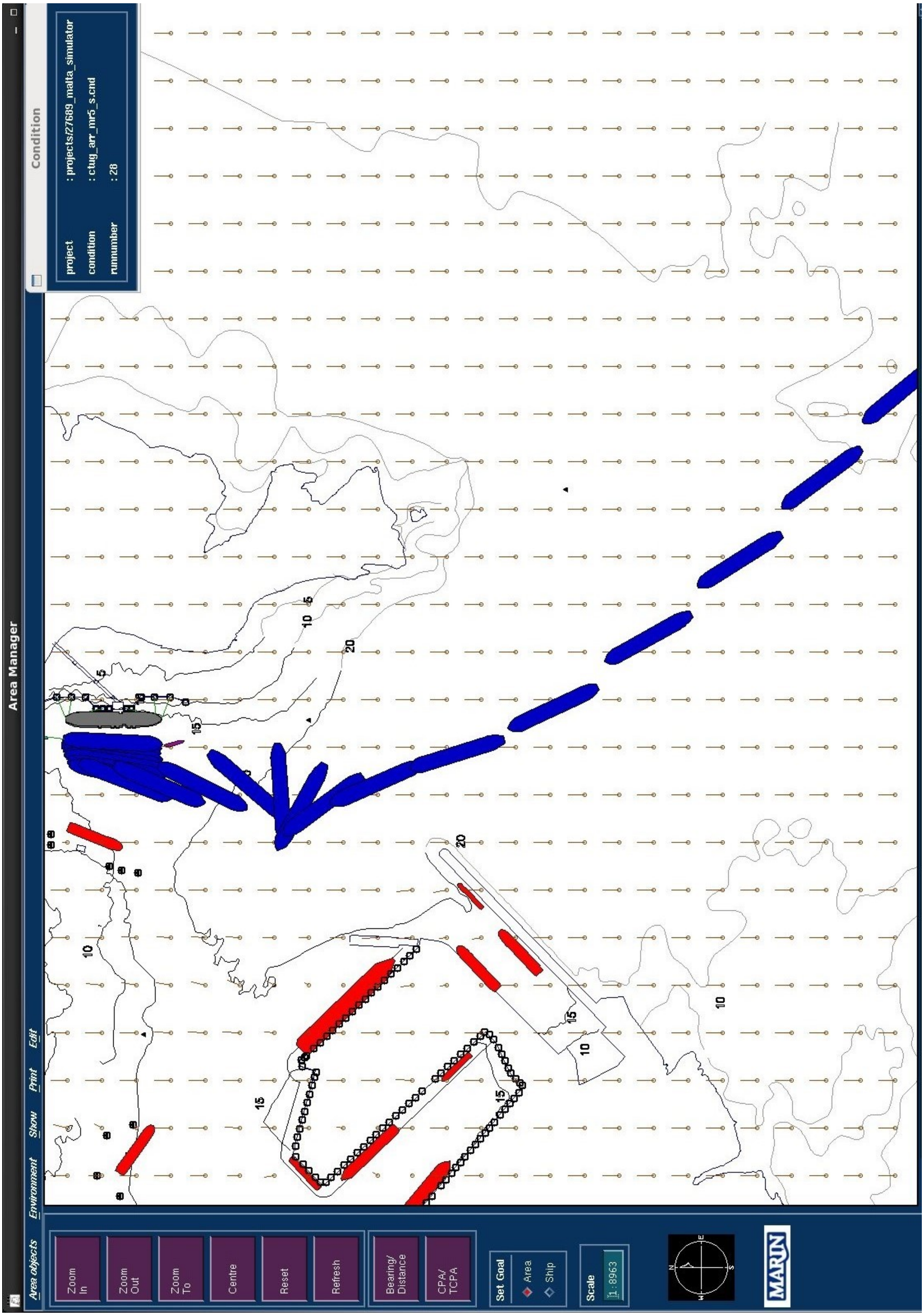
Plot C-14 Trackplot of run 24



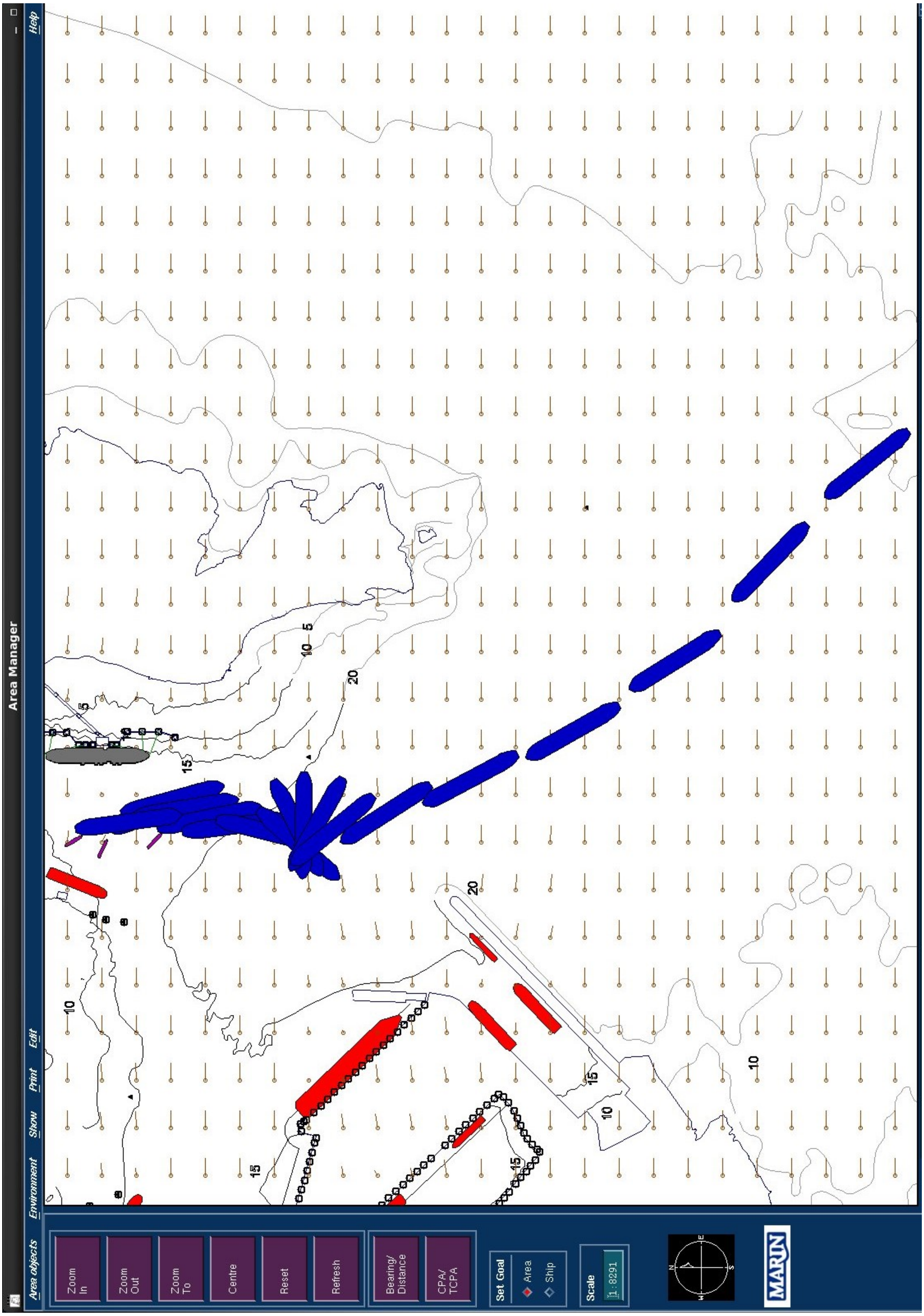
Plot C-15 Trackplot of run 25



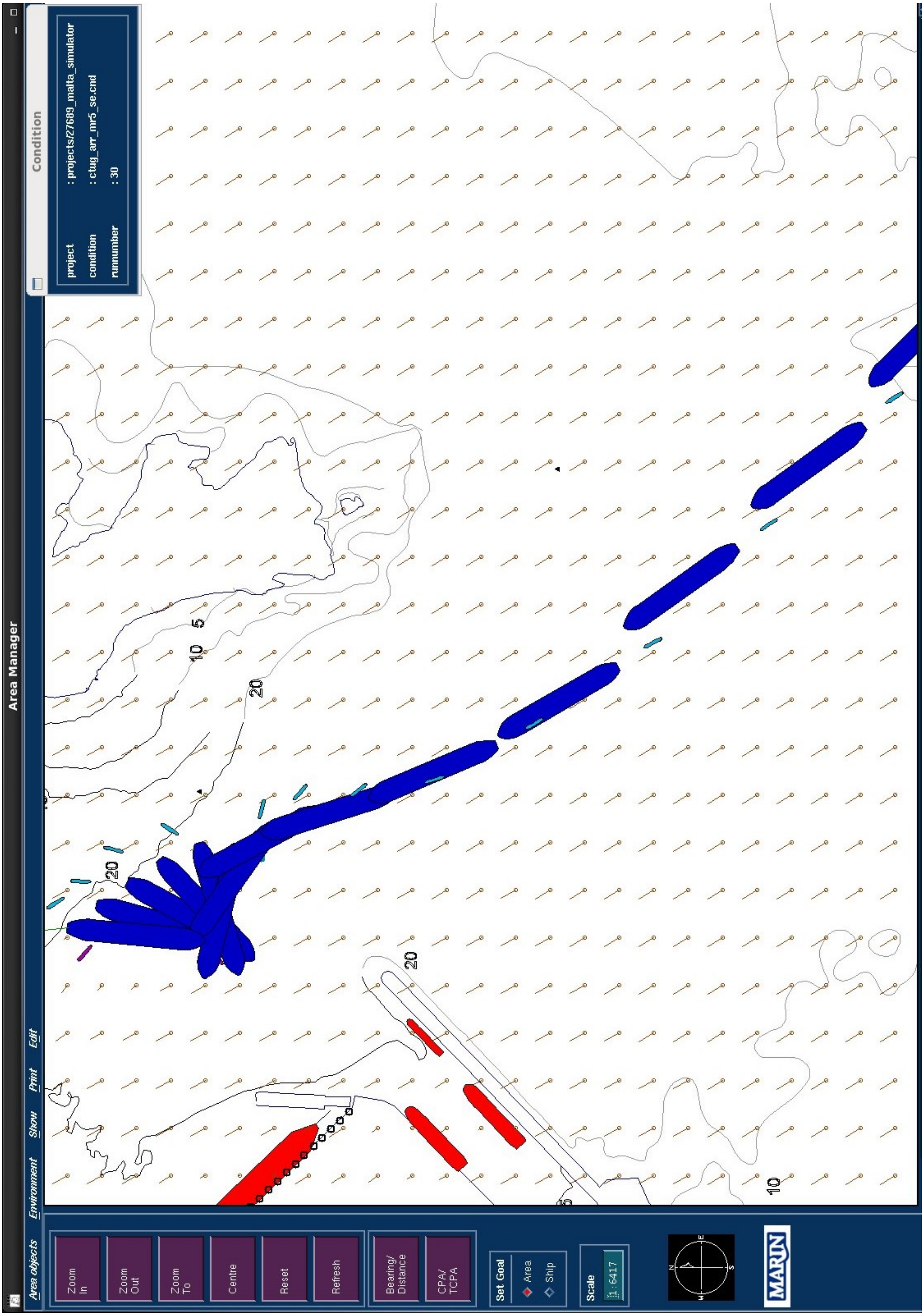
Plot C-16 Trackplot of run 27



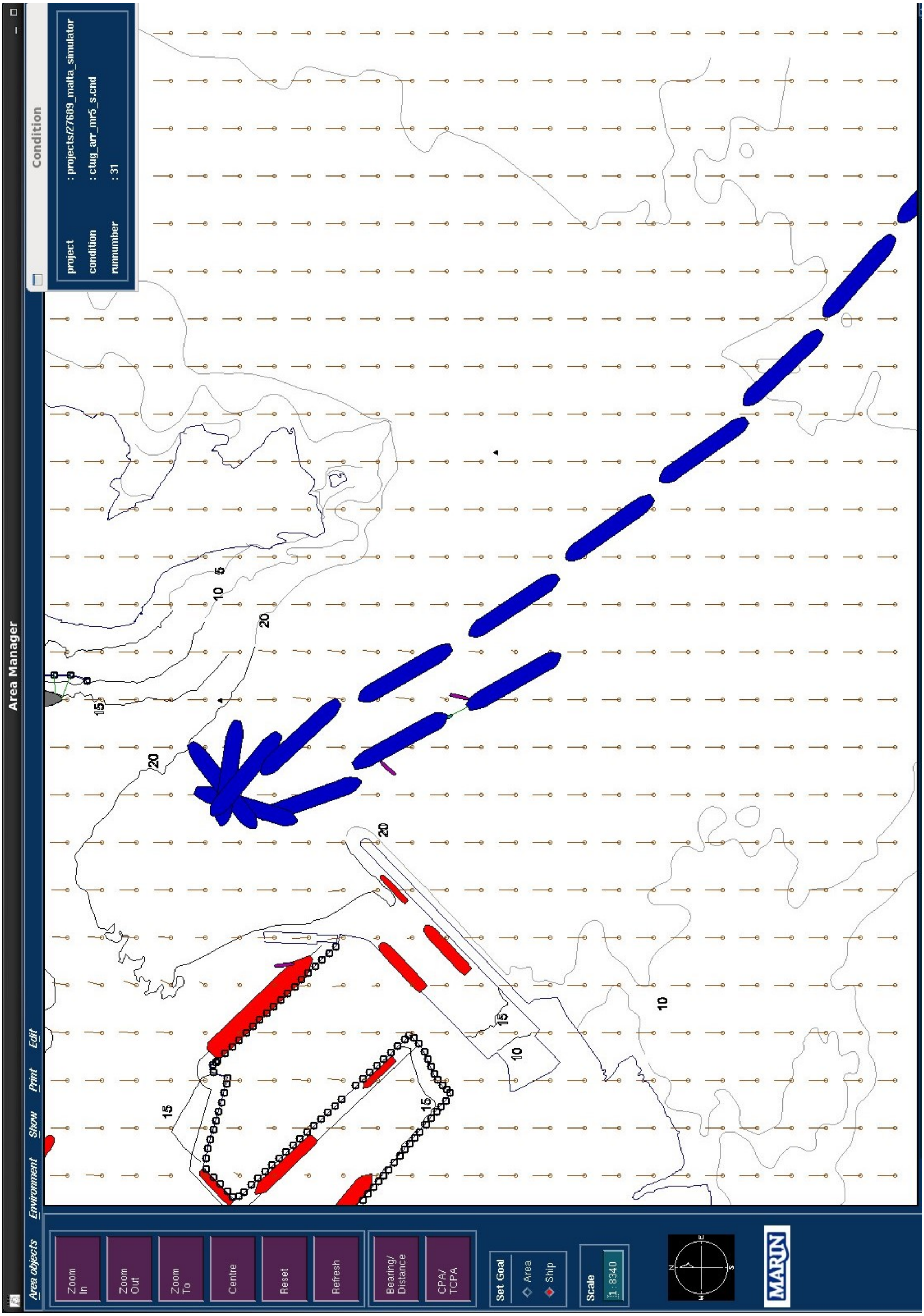
Plot C-17 Trackplot of run 28



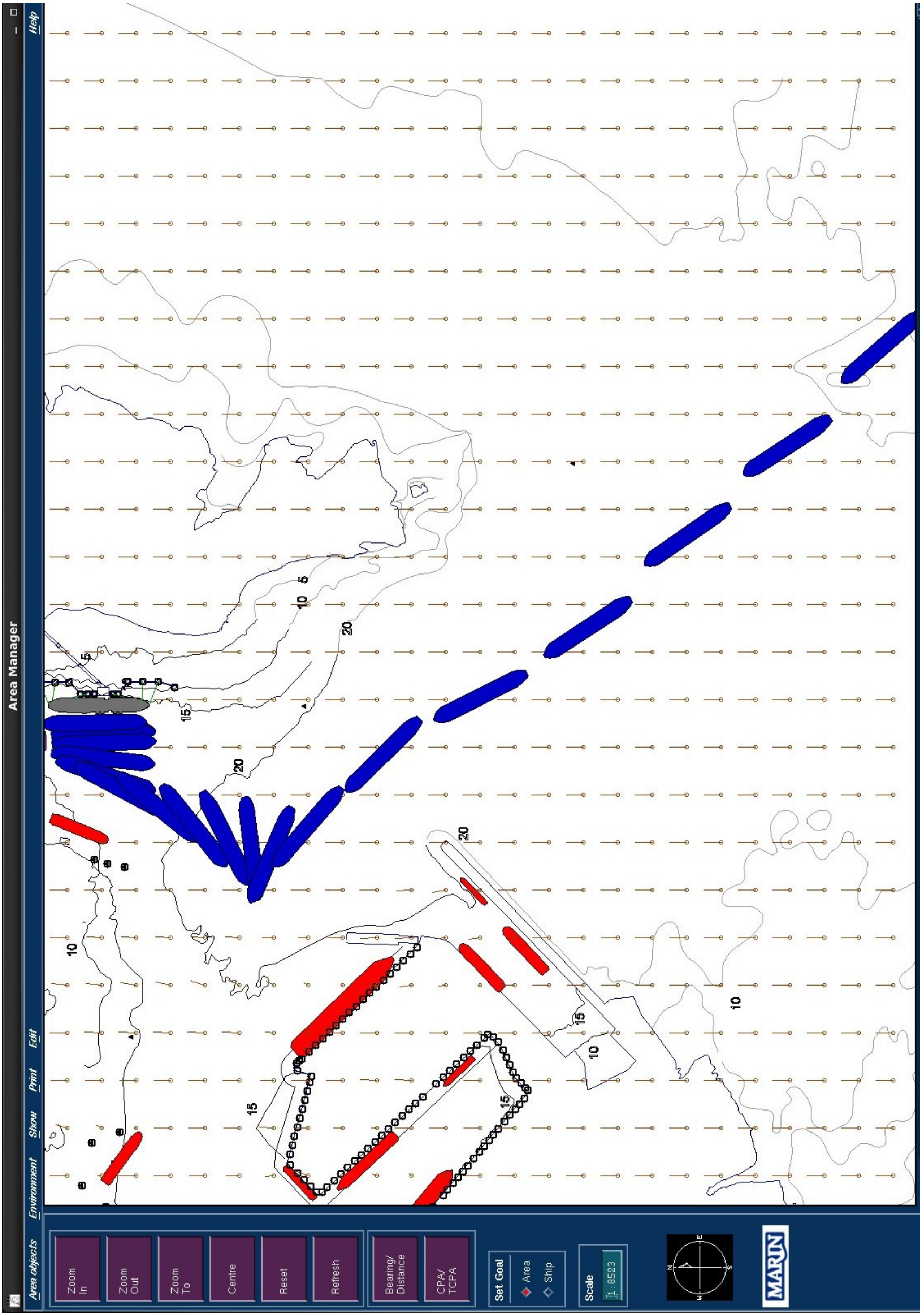
Plot C-18 Trackplot of run 29



Plot C-19 Trackplot of run 30

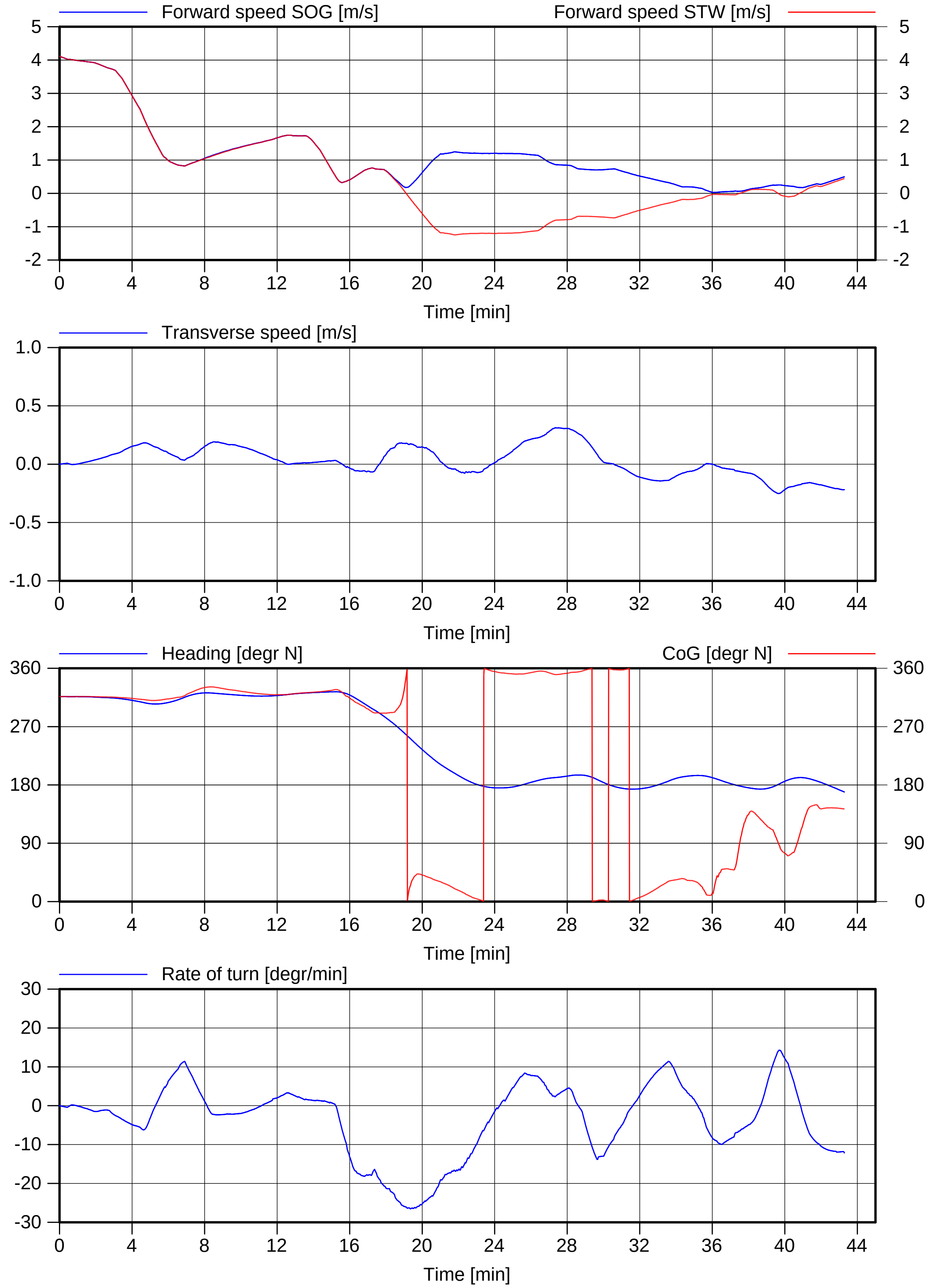


Plot C-20 Trackplot of run 31

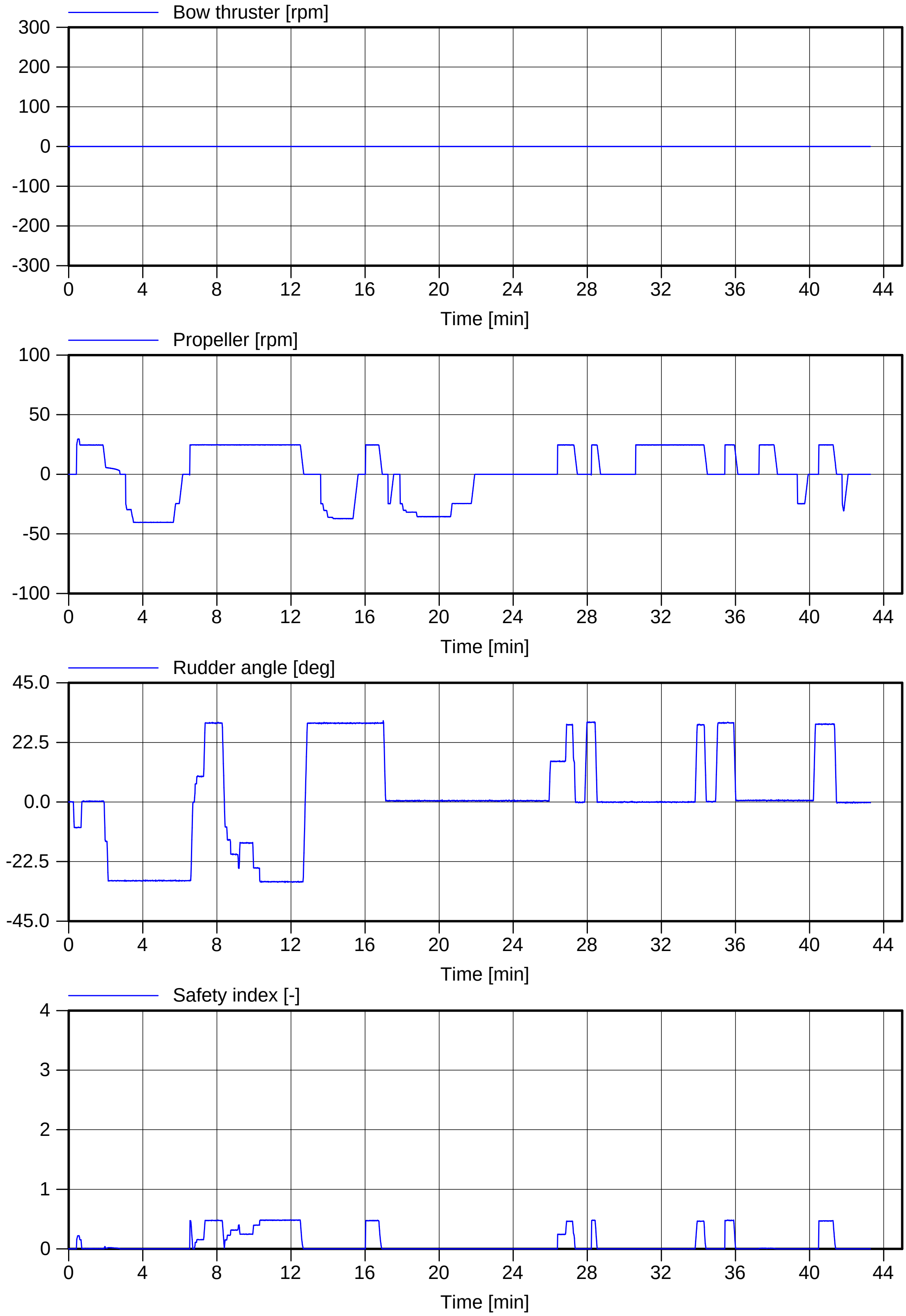


Plot C-21 Trackplot of run 33

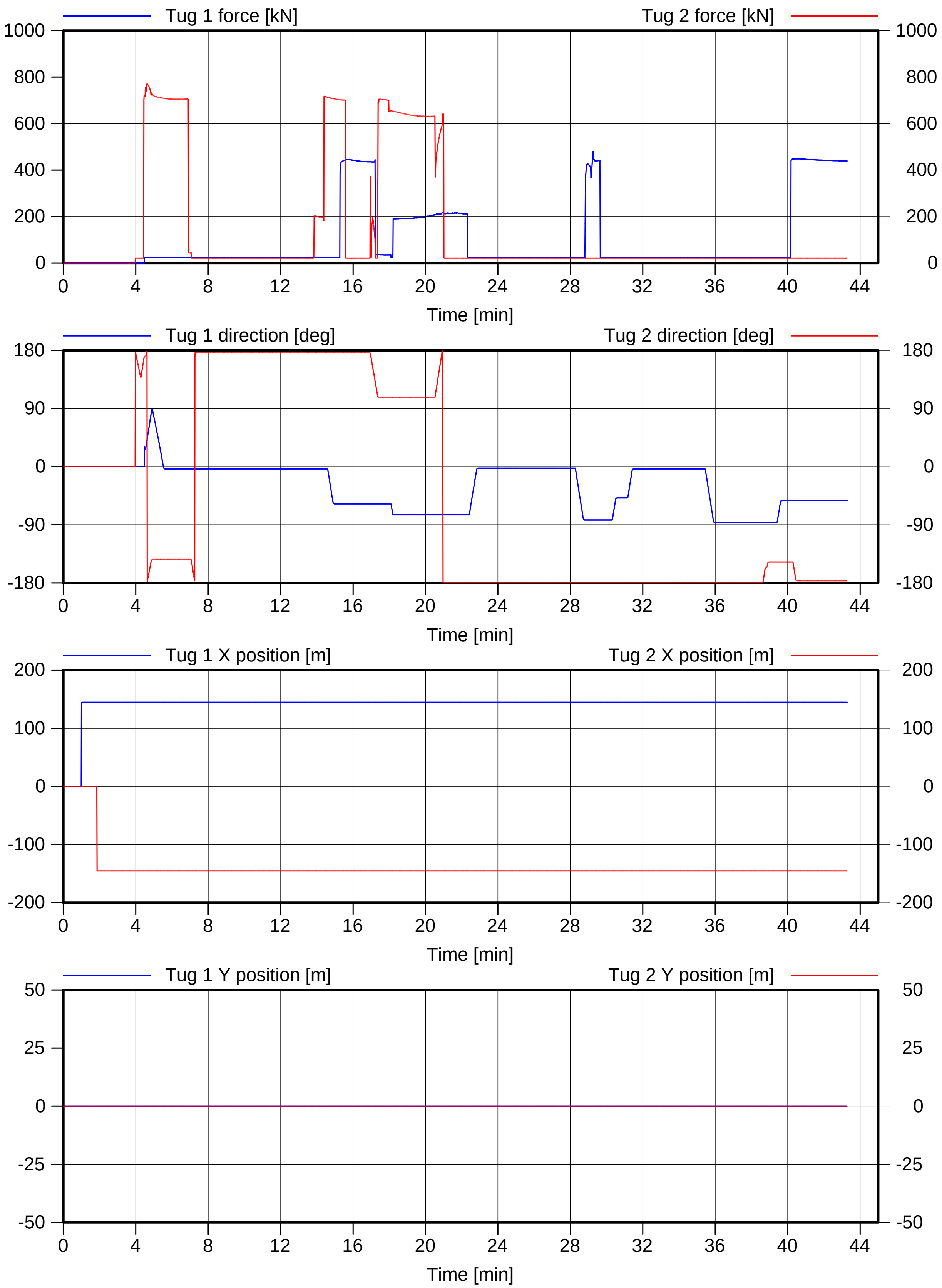
APPENDIX D: DATAPLOTS OF REAL-TIME SIMULATIONS



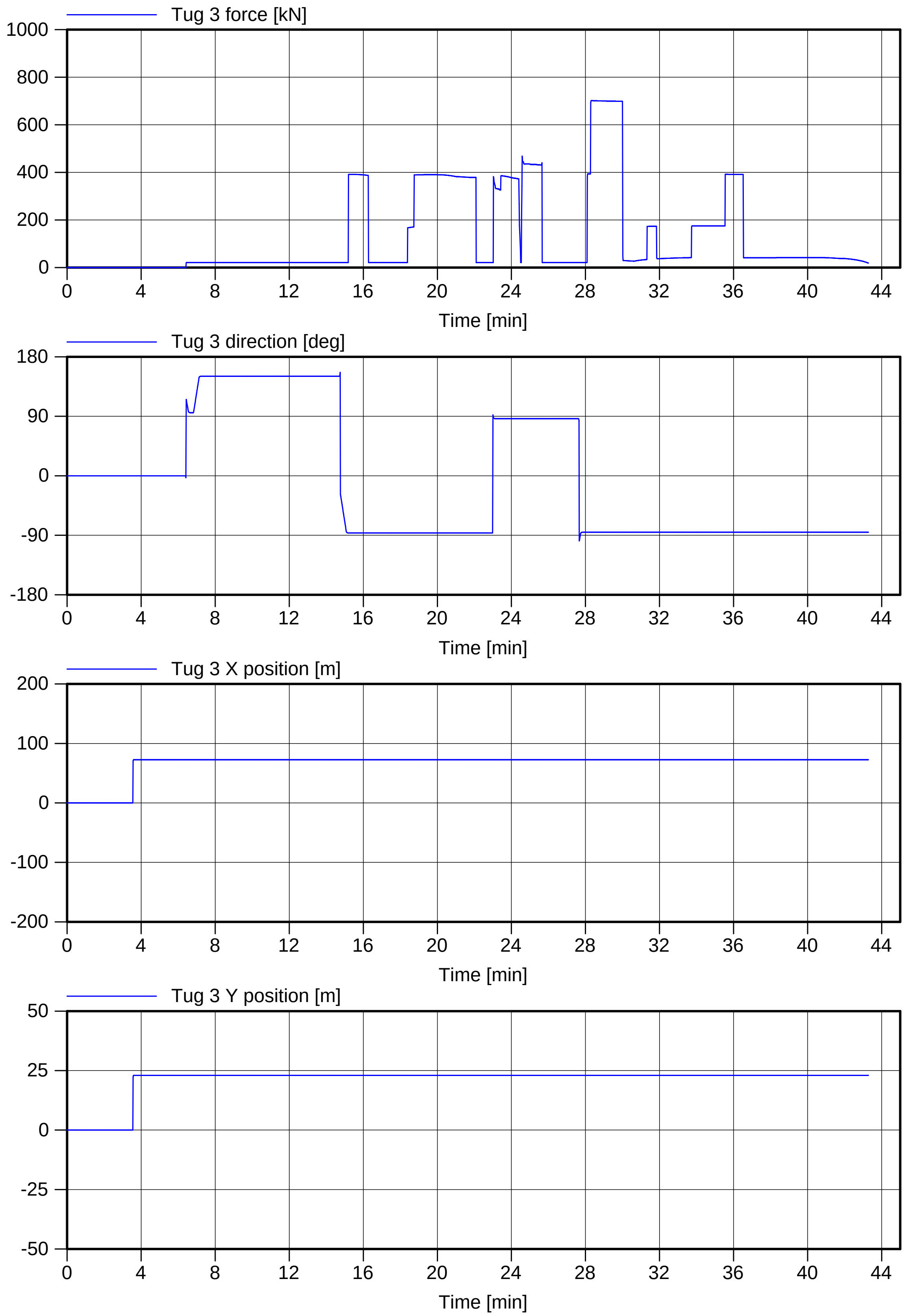
Run: 9	Malta
Arrival	Wind 10m/s from SE
MARIN's Nautical Centre MSCN	Fig. 1.a



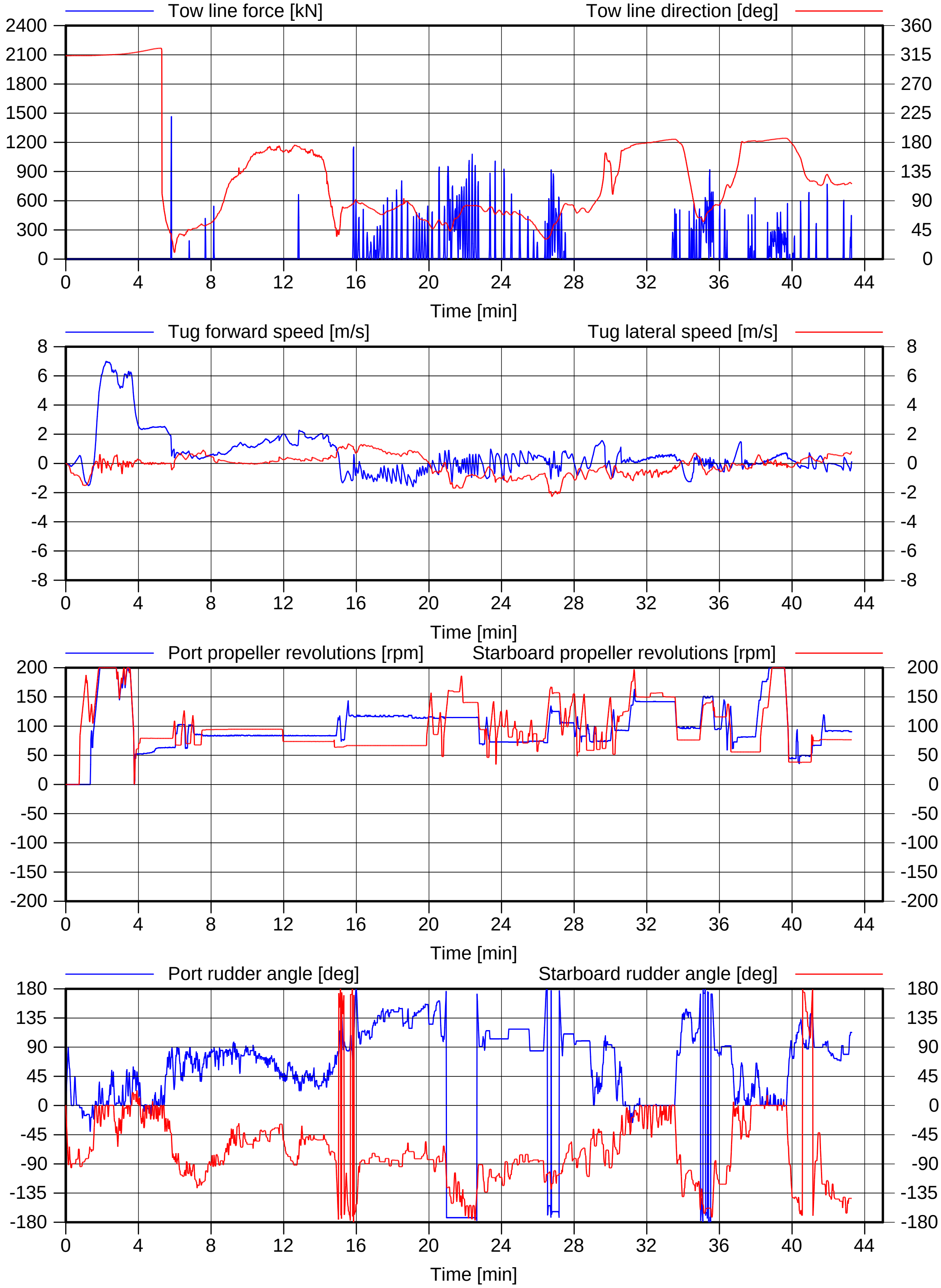
Run: 9	Malta
Arrival	Wind 10m/s from SE
MARIN's Nautical Centre MSCN	Fig. 1.b



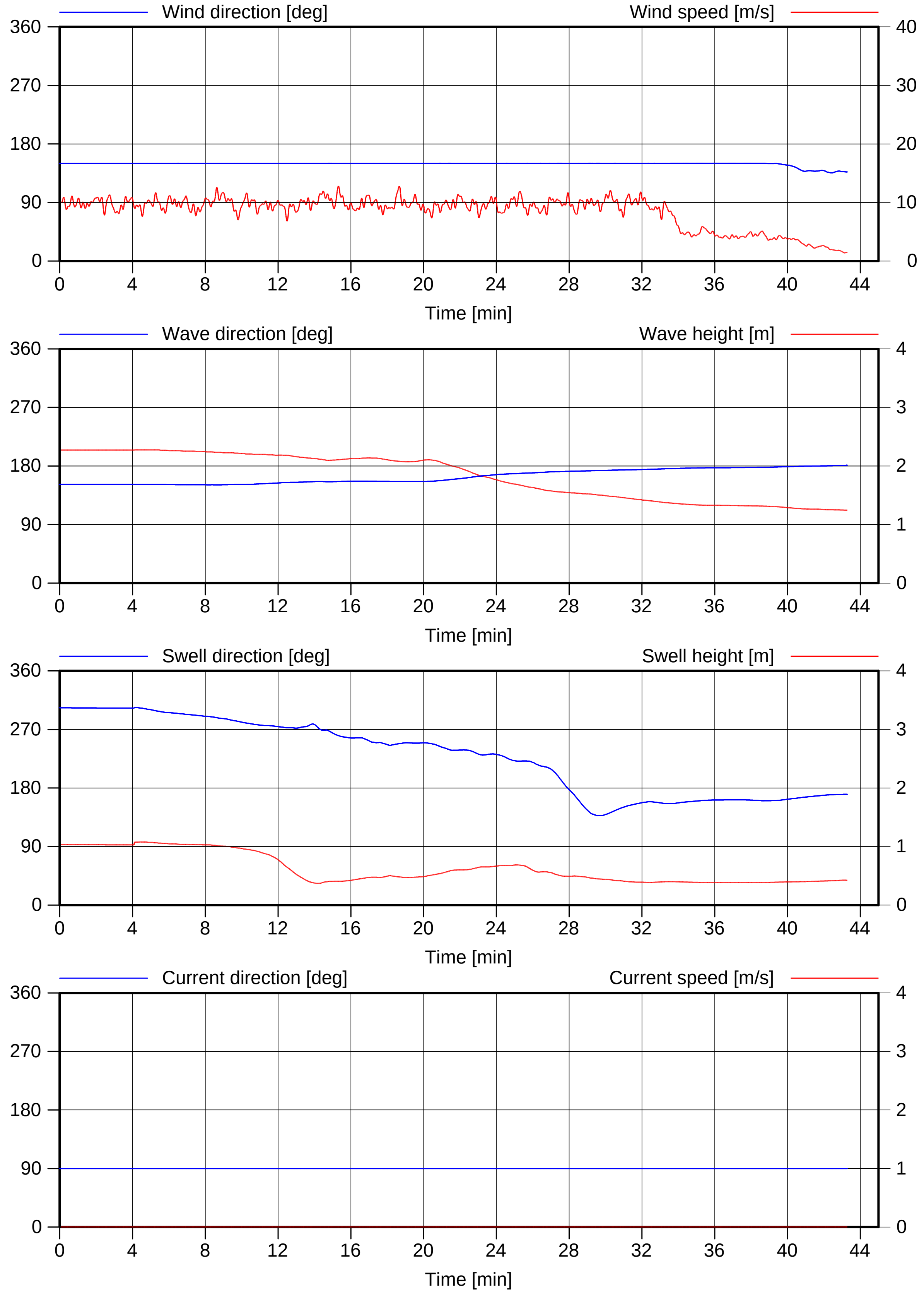
Run: 9	Malta
Arrival	Wind 10m/s from SE
MARIN's Nautical Centre MSCN	Fig. 1.c



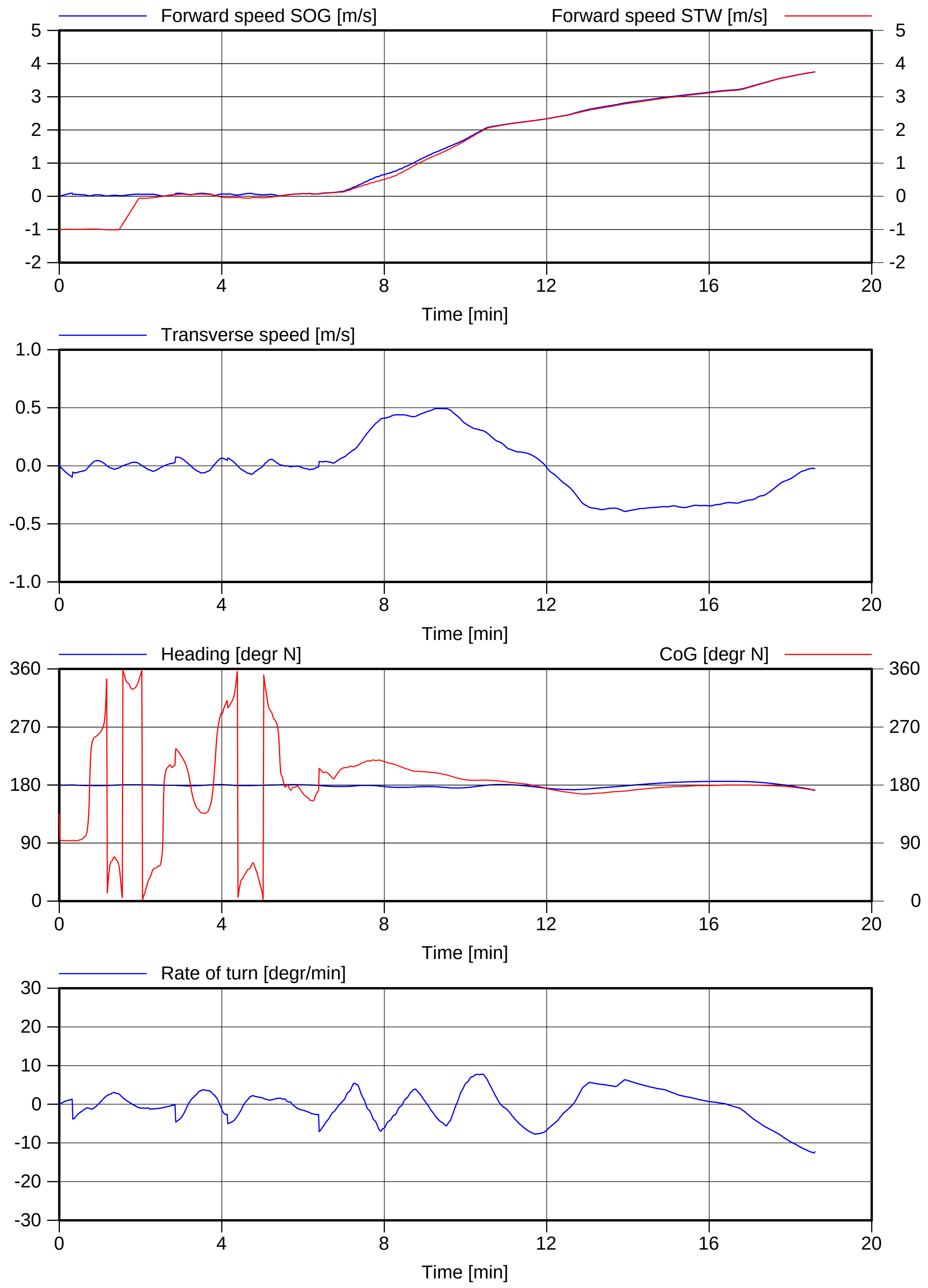
Run: 9	Malta
Arrival	Wind 10m/s from SE
MARIN's Nautical Centre MSCN	Fig. 1.d



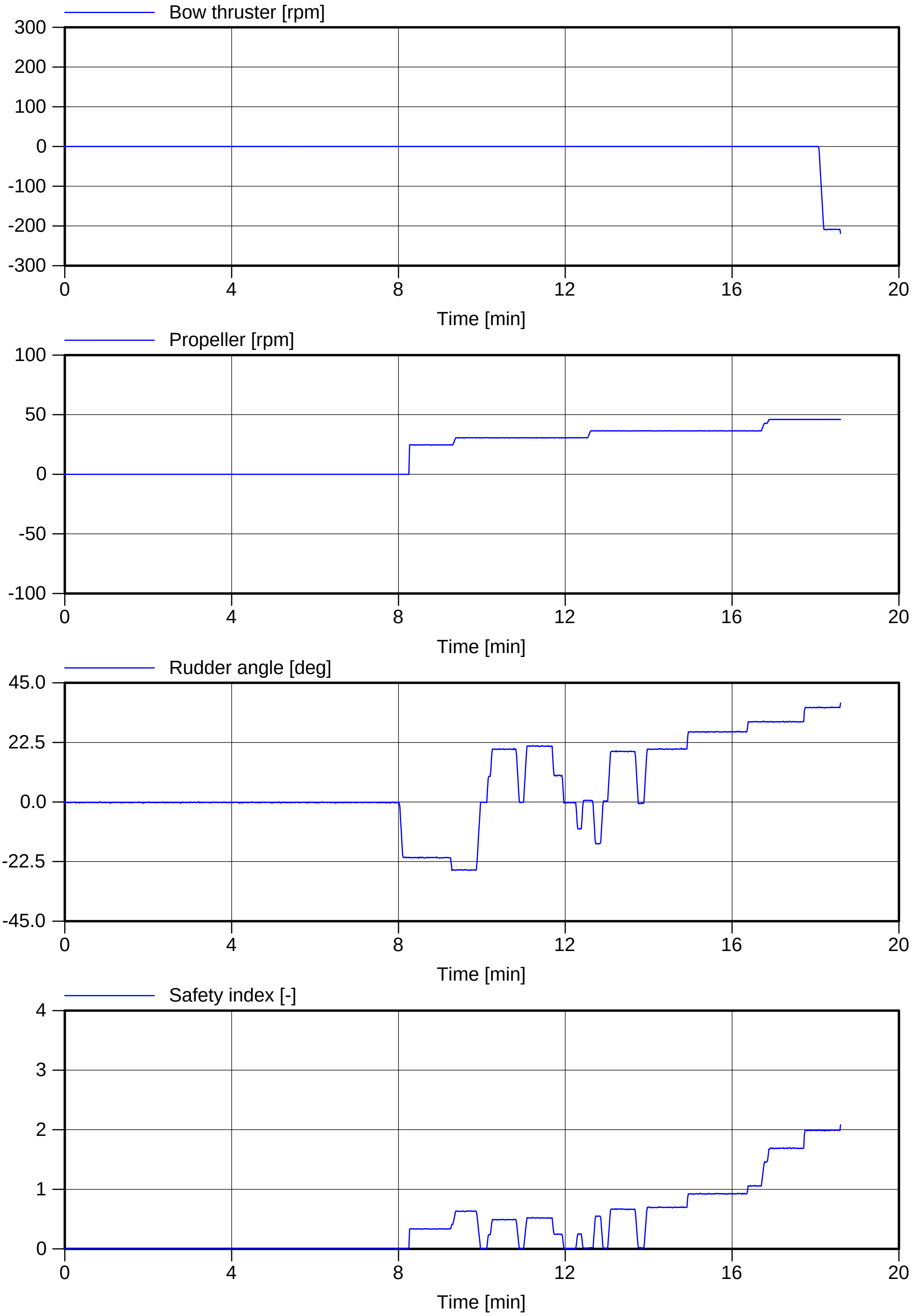
Run: 9	Malta
Arrival	Wind 10m/s from SE
MARIN's Nautical Centre MSCN	Fig. 1.e



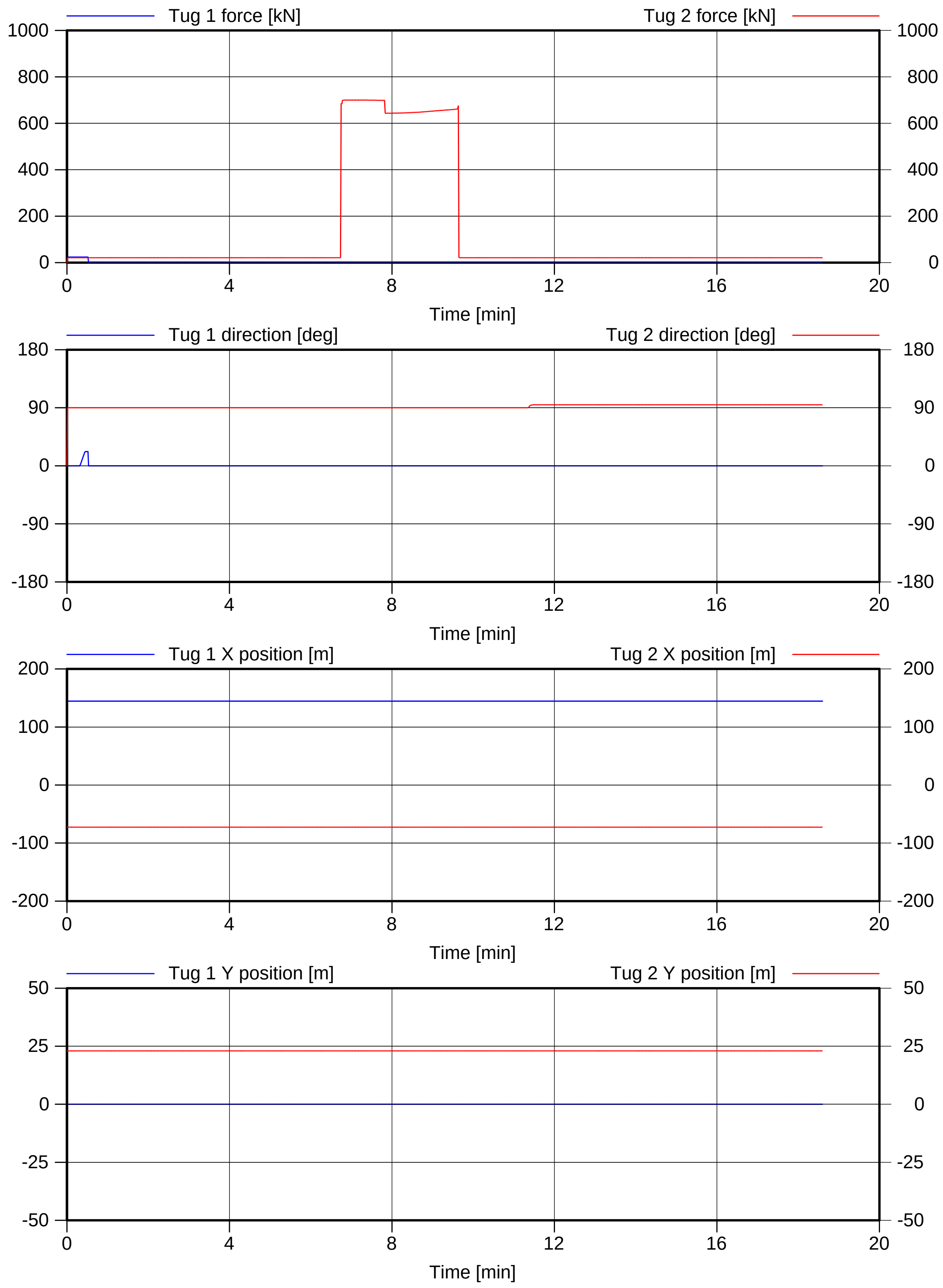
Run: 9	Malta
Arrival	Wind 10m/s from SE
MARIN's Nautical Centre MSCN	Fig. 1.f



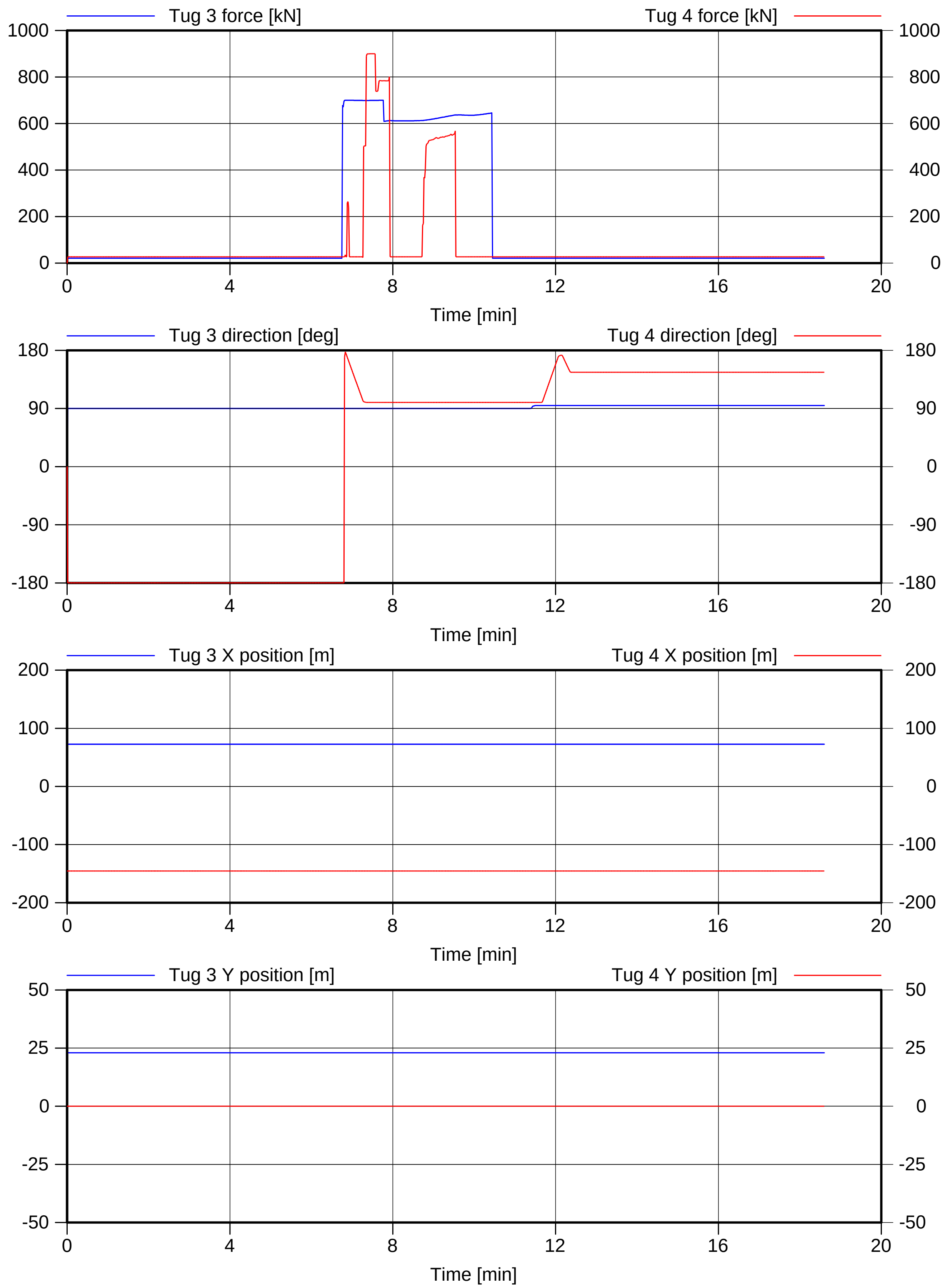
Run: 10	Malta
Departure	Wind 14m/s from W
MARIN's Nautical Centre MSCN	Fig. 2.a



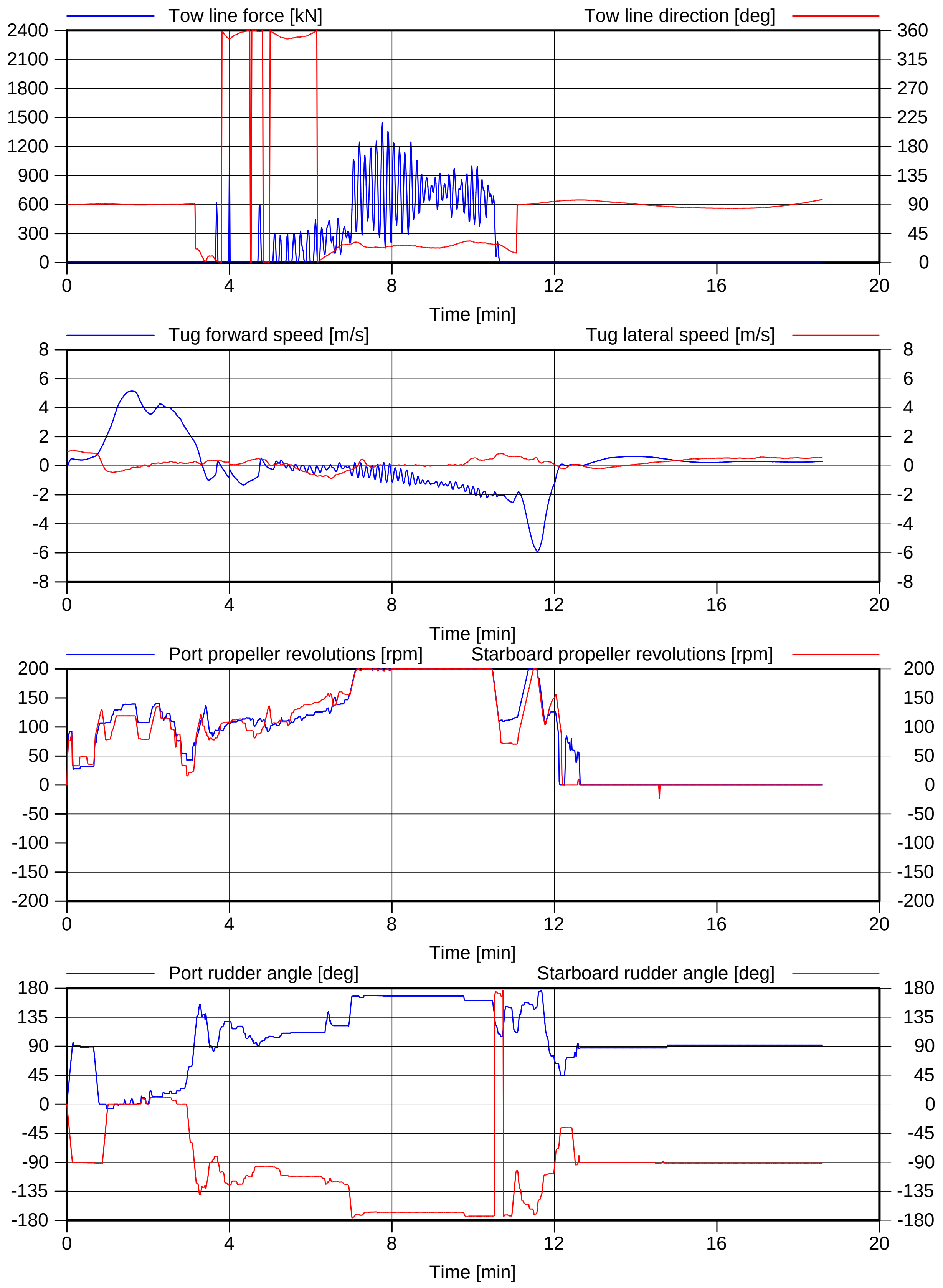
Run: 10	Malta
Departure	Wind 14m/s from W
MARIN's Nautical Centre MSCN	Fig. 2.b



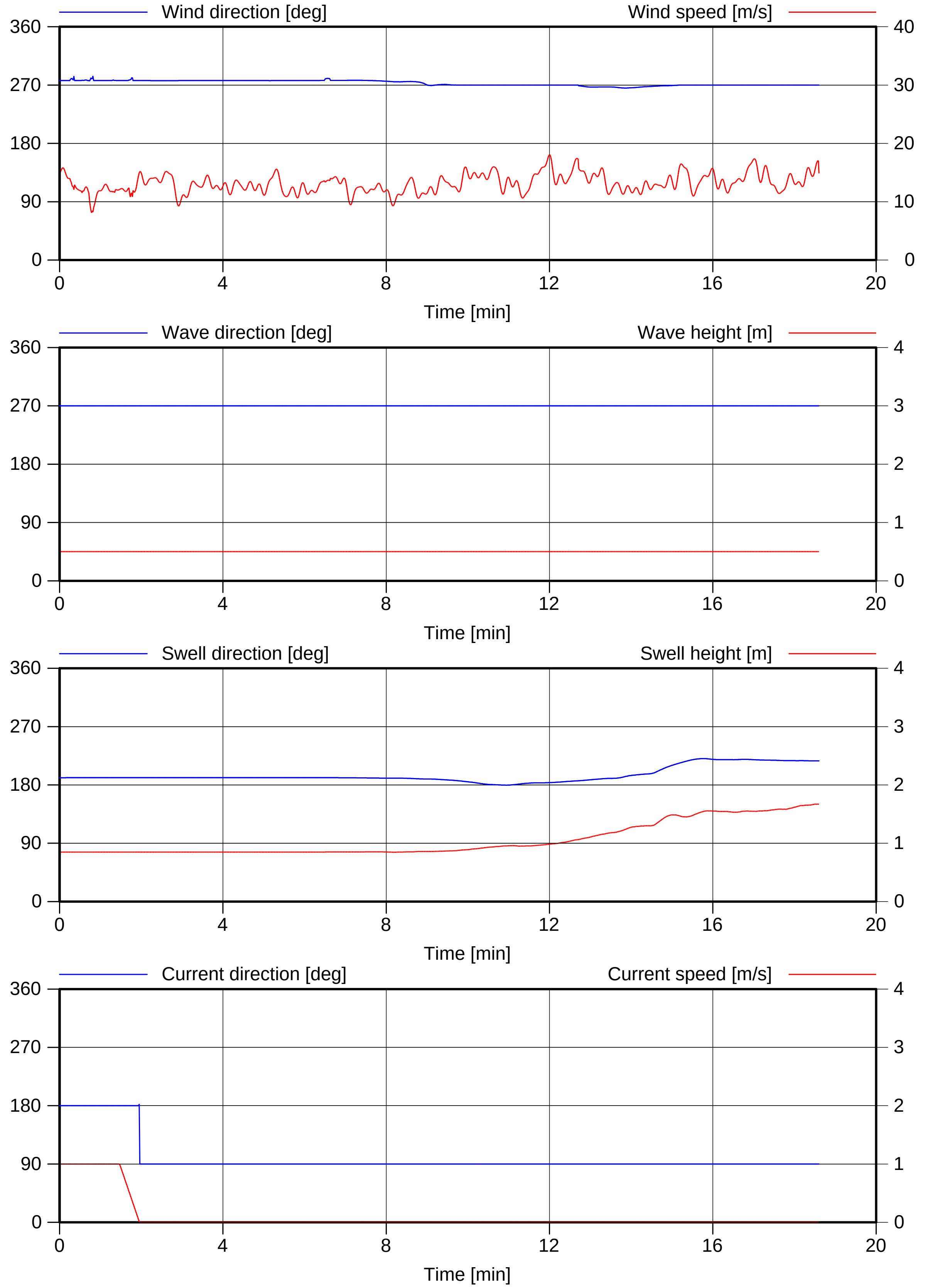
Run: 10	Malta
Departure	Wind 14m/s from W
MARIN's Nautical Centre MSCN	Fig. 2.c



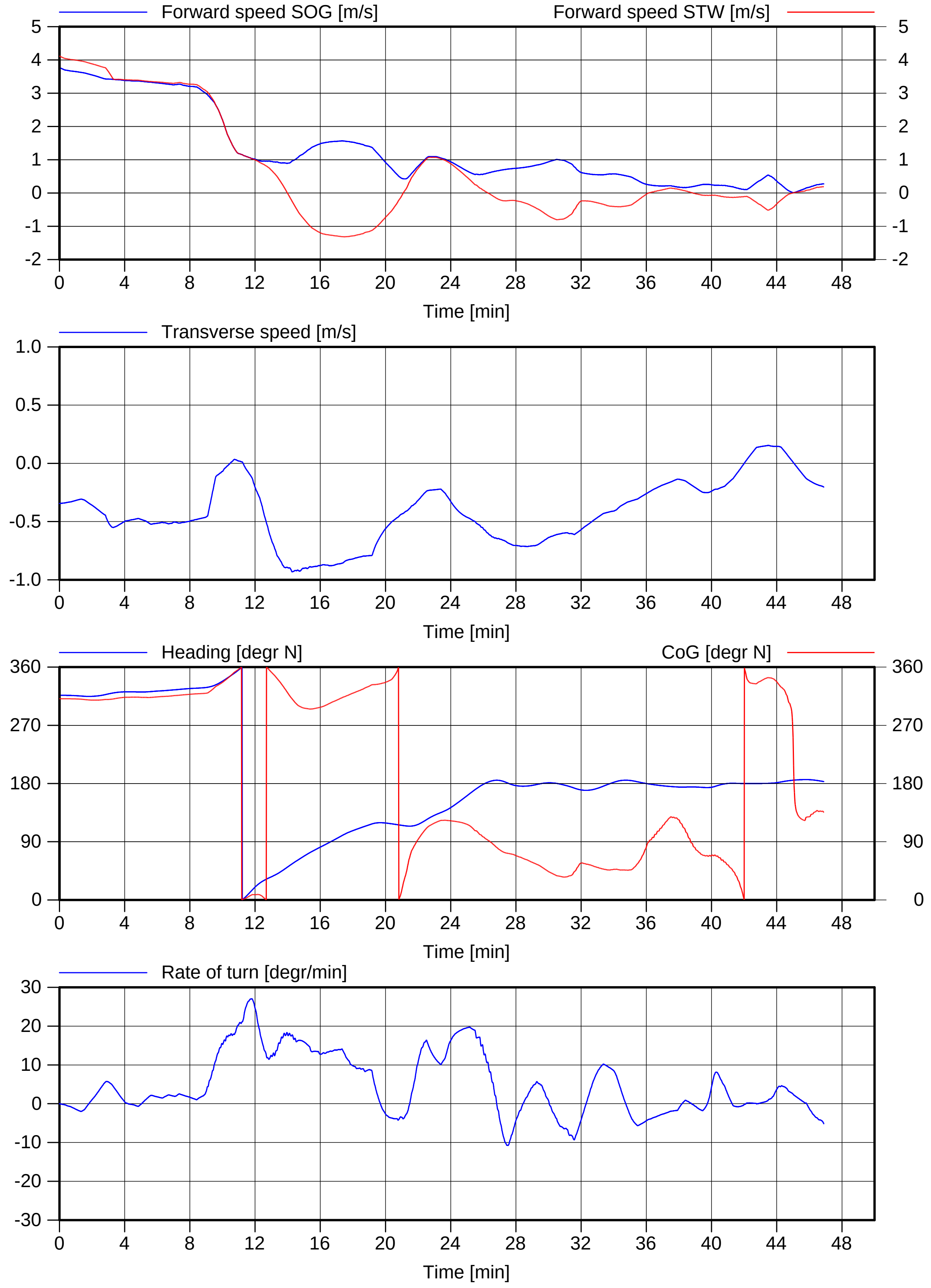
Run: 10	Malta
Departure	Wind 14m/s from W
MARIN's Nautical Centre MSCN	Fig. 2.d



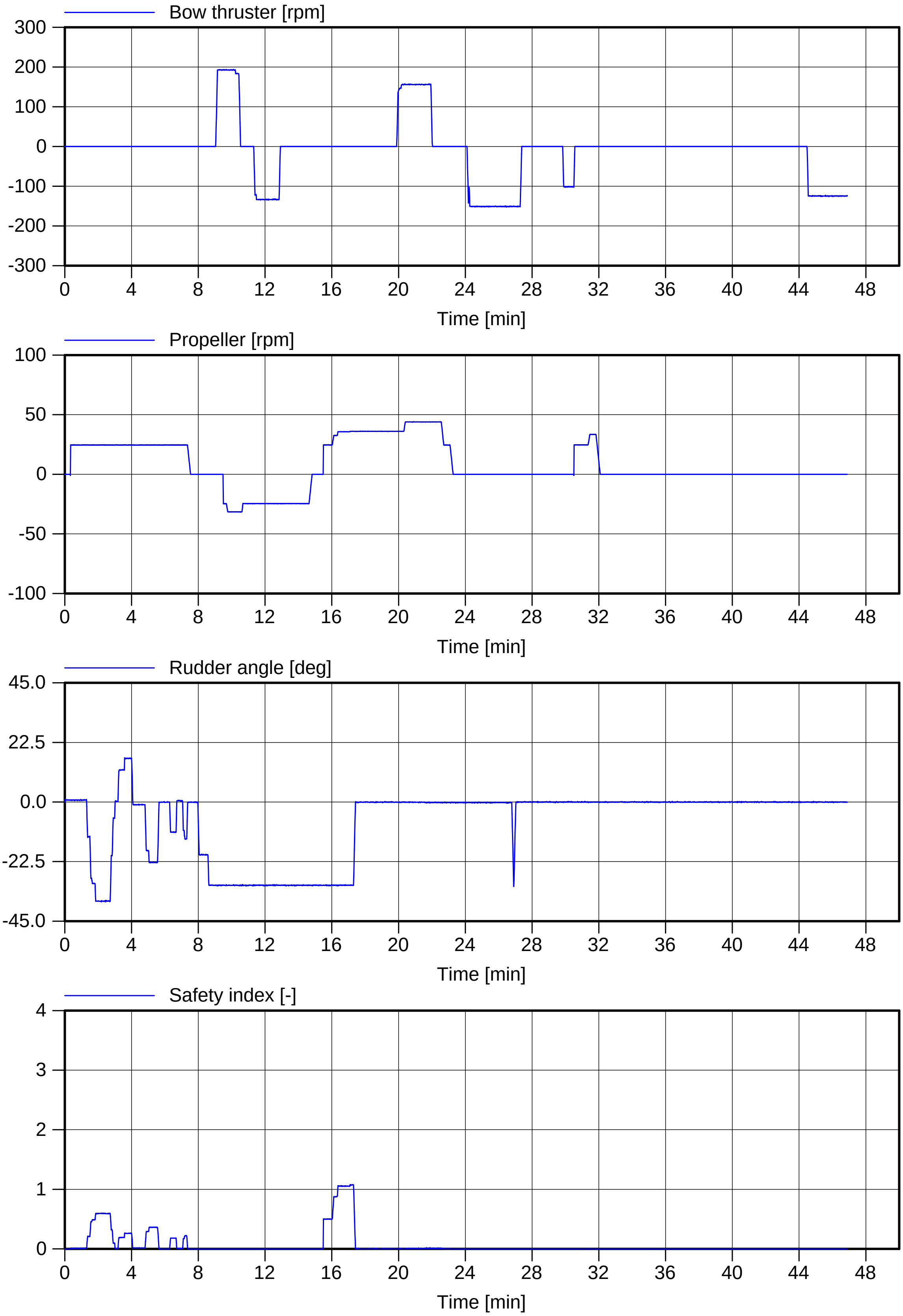
Run: 10	Malta
Departure	Wind 14m/s from W
MARIN's Nautical Centre MSCN	Fig. 2.e



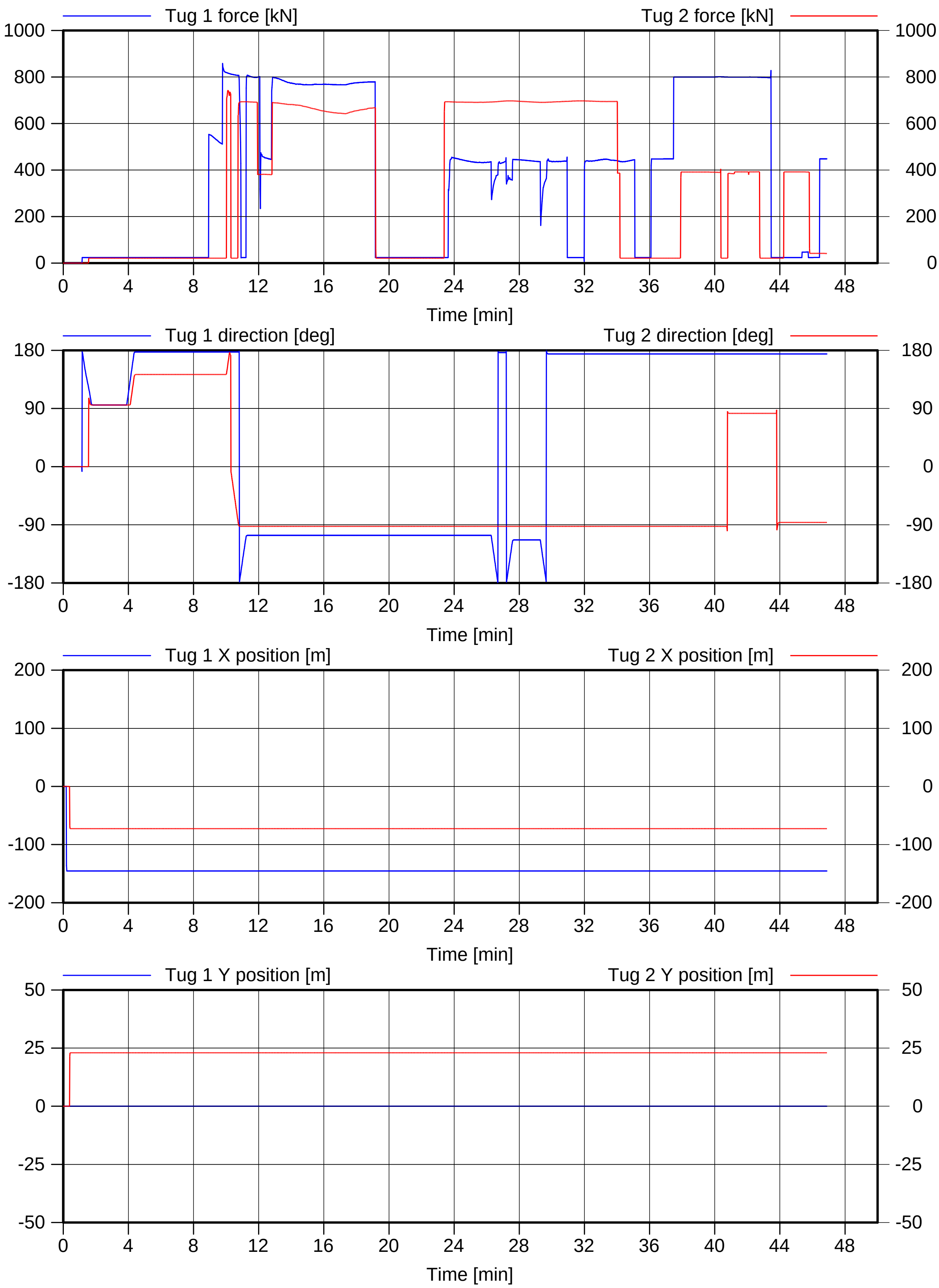
Run: 10	Malta
Departure	Wind 14m/s from W
MARIN's Nautical Centre MSCN	Fig. 2.f



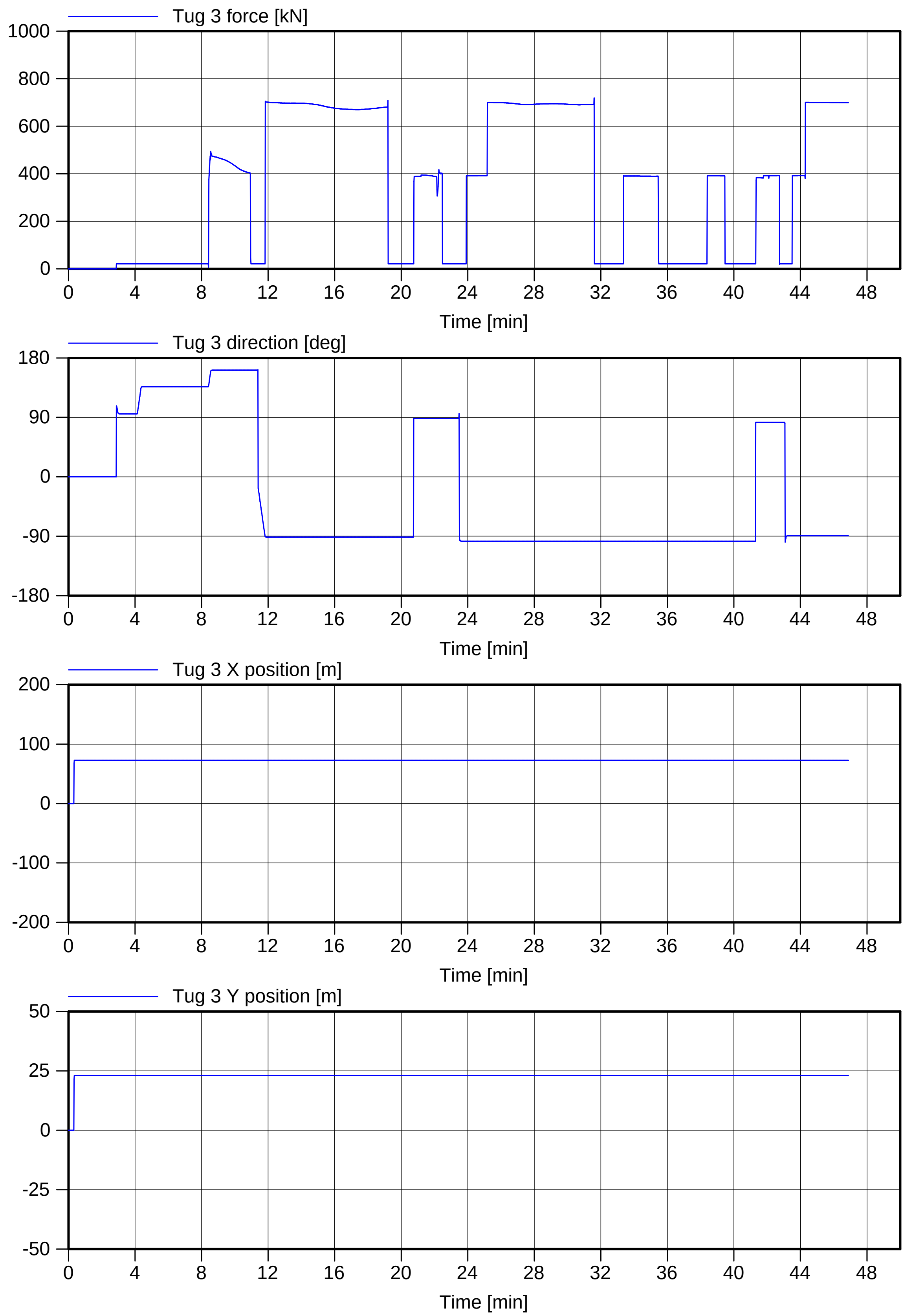
Run: 11	Malta
Arrival	Wind 10m/s from SE
MARIN's Nautical Centre MSCN	Fig. 3.a



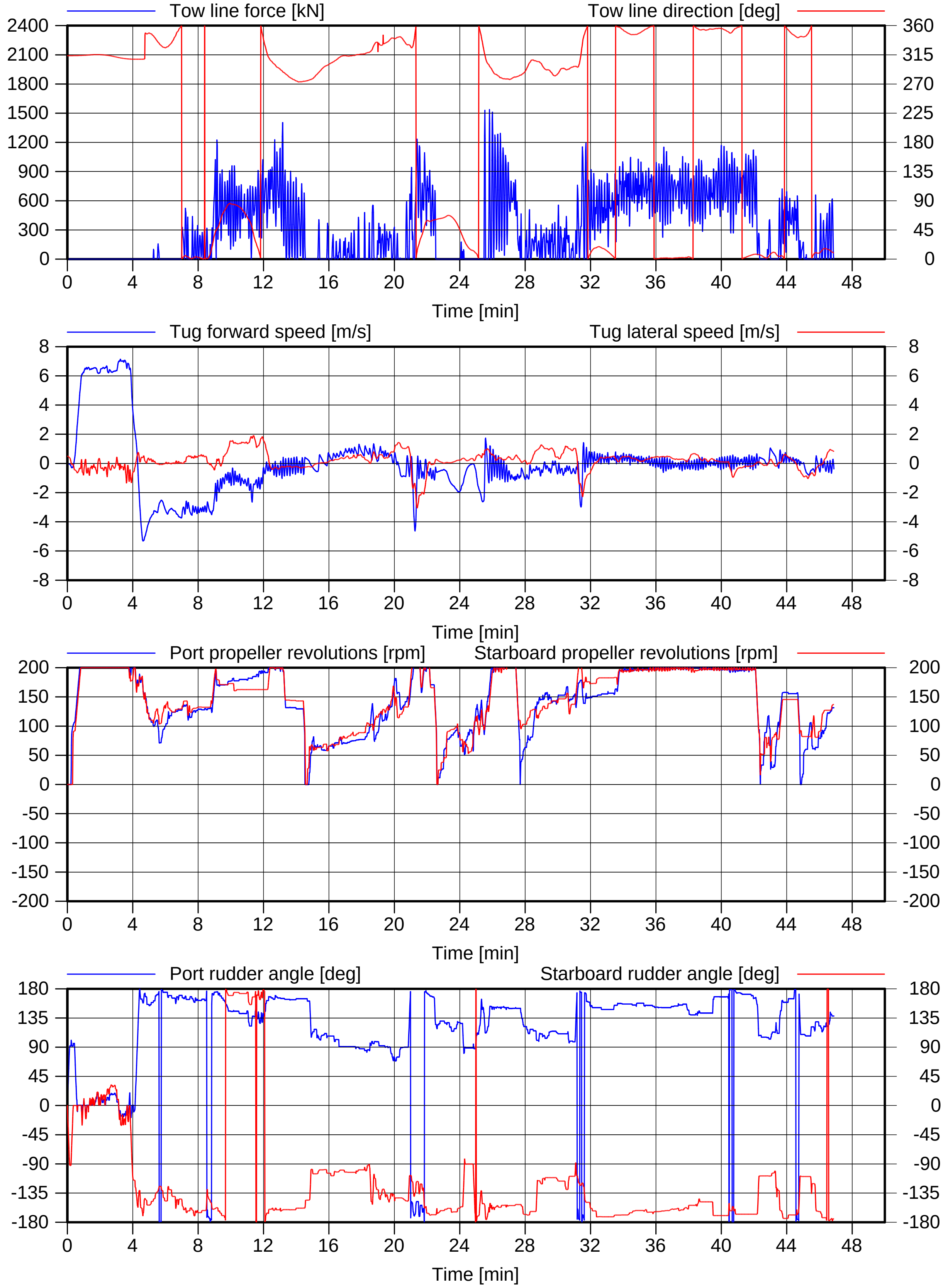
Run: 11	Malta
Arrival	Wind 10m/s from SE
MARIN's Nautical Centre MSCN	Fig. 3.b



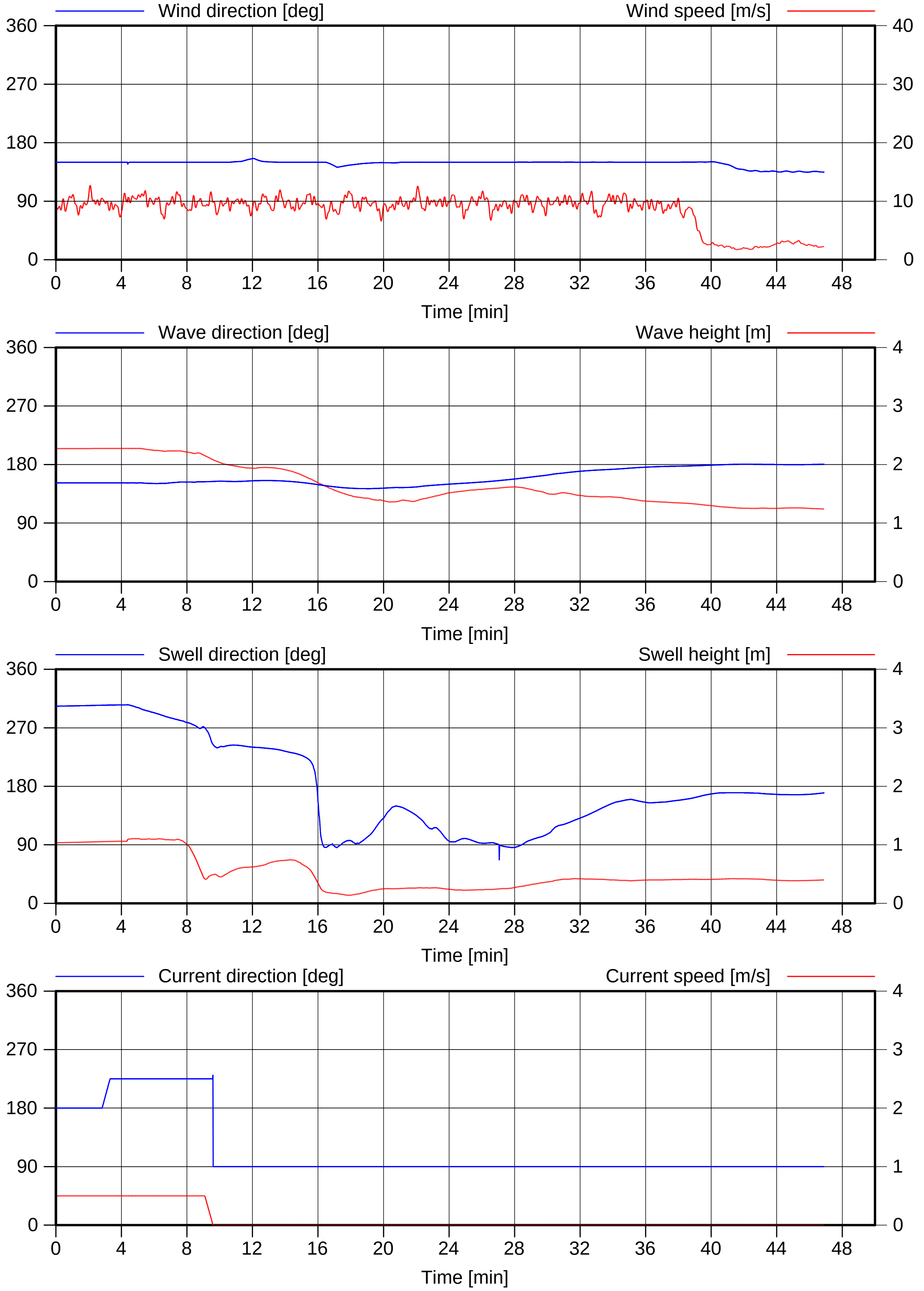
Run: 11	Malta
Arrival	Wind 10m/s from SE
MARIN's Nautical Centre MSCN	Fig. 3.c



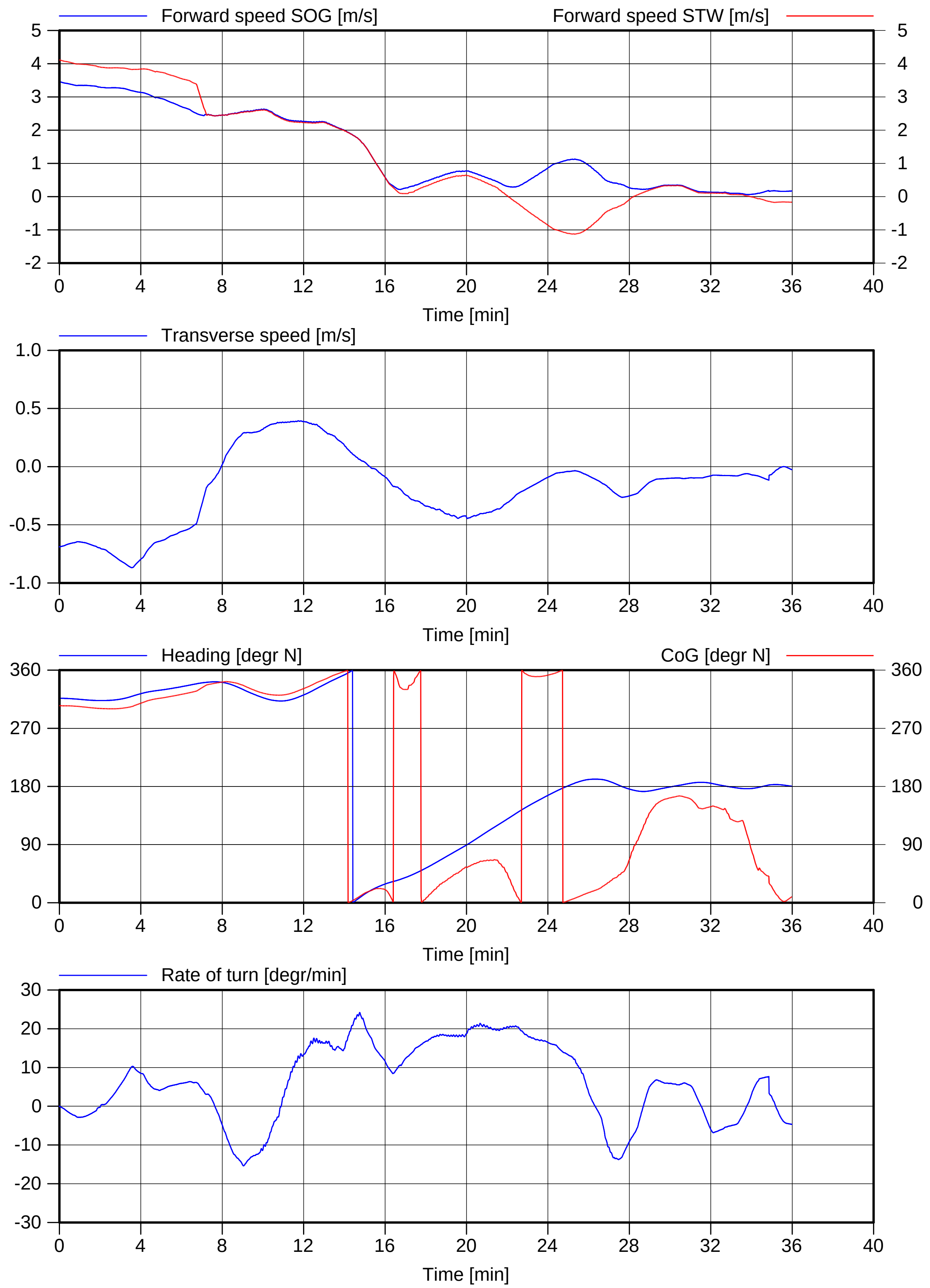
Run: 11	Malta
Arrival	Wind 10m/s from SE
MARIN's Nautical Centre MSCN	Fig. 3.d



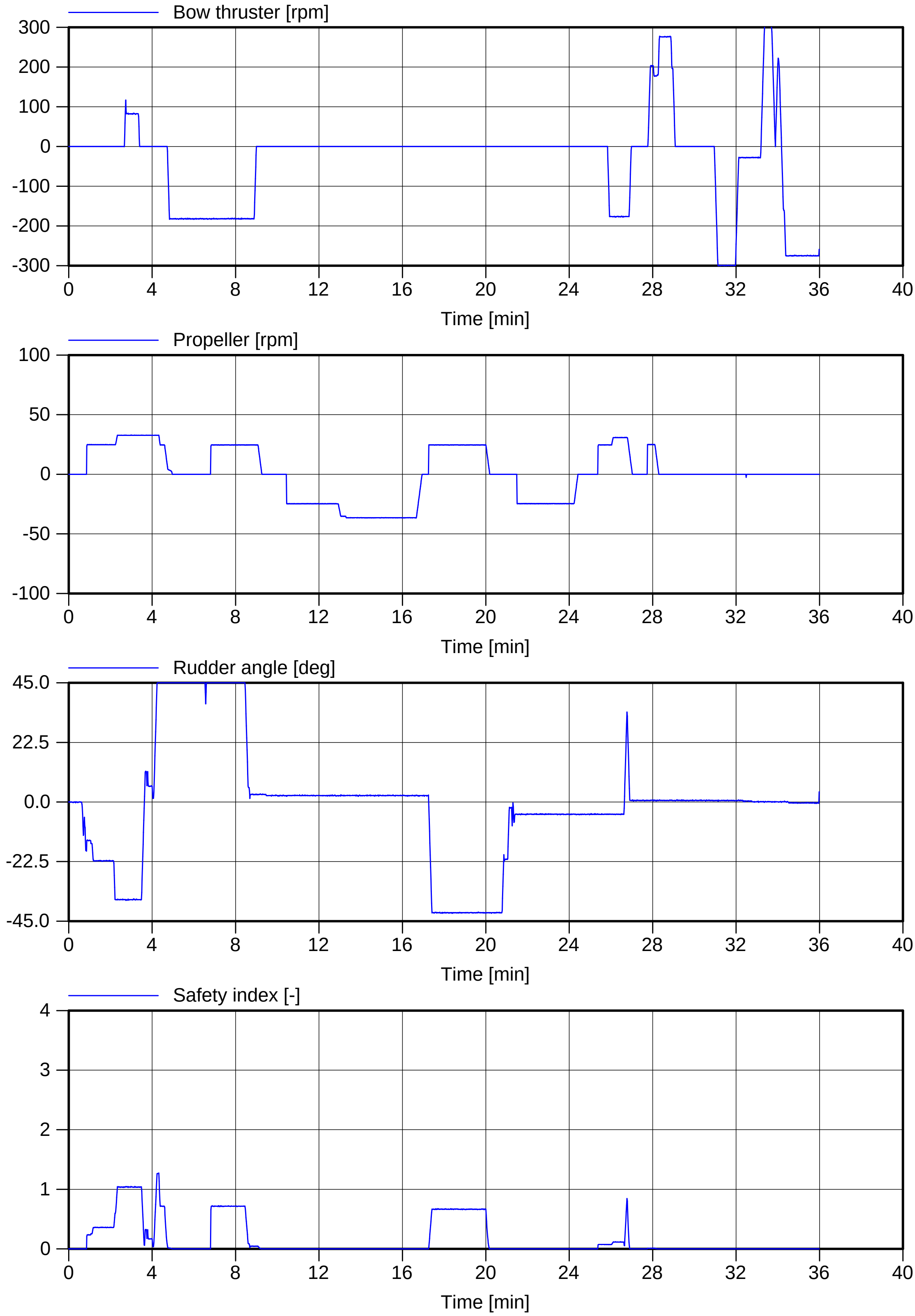
Run: 11	Malta
Arrival	Wind 10m/s from SE
MARIN's Nautical Centre MSCN	Fig. 3.e



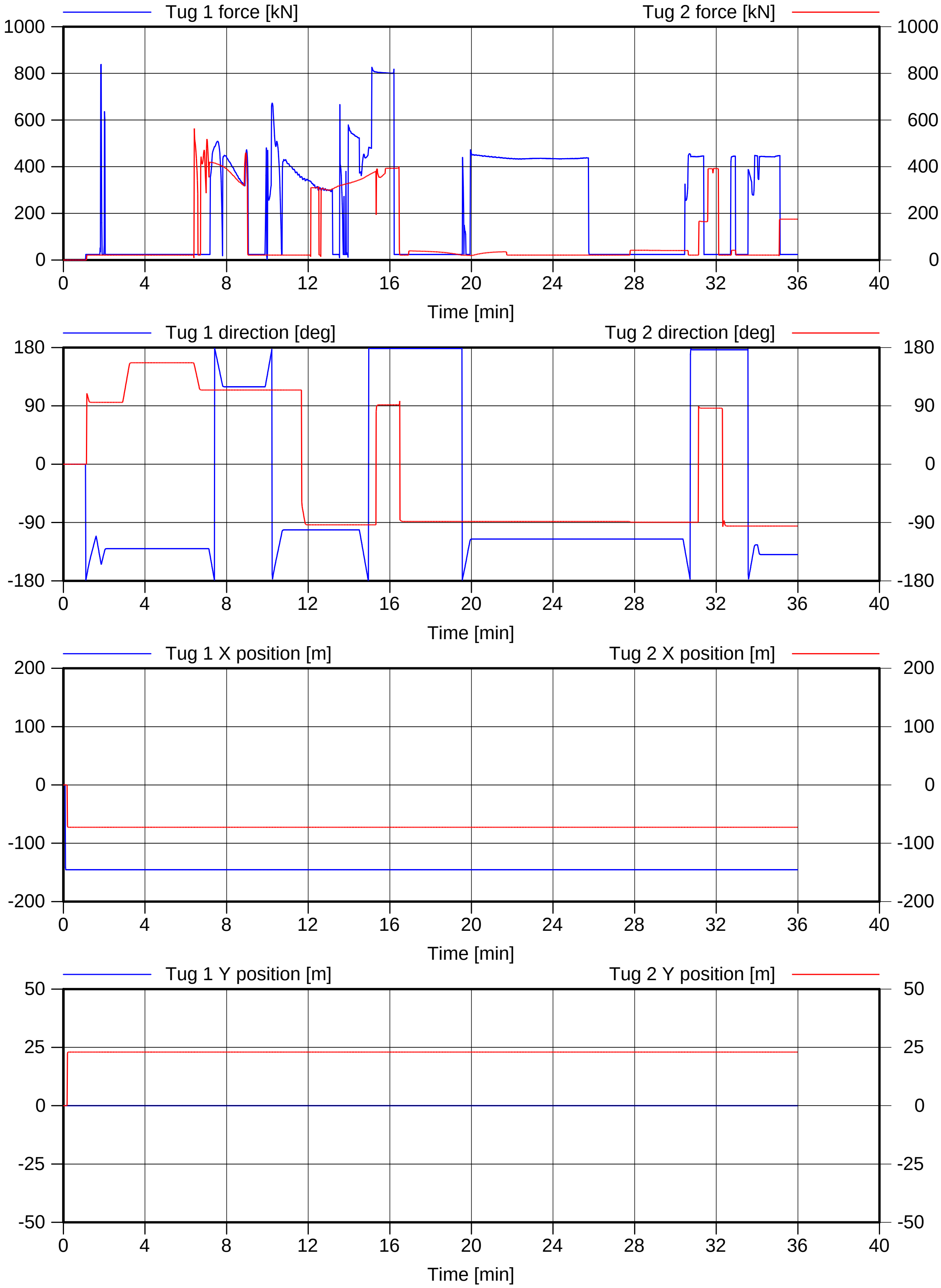
Run: 11	Malta
Arrival	Wind 10m/s from SE
MARIN's Nautical Centre MSCN	Fig. 3.f



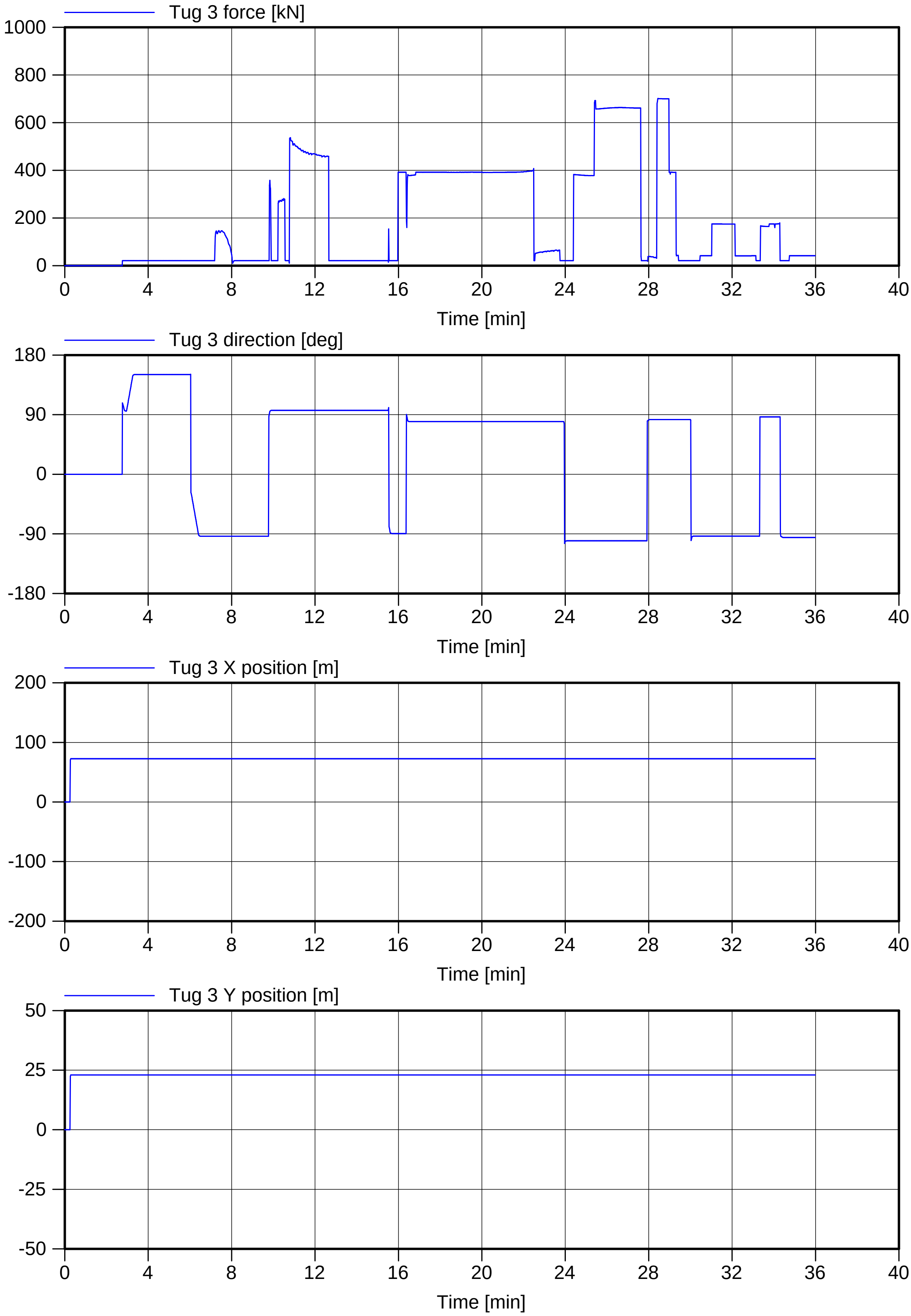
Run: 12	Malta
Arrival	Wind 10m/s from SE
MARIN's Nautical Centre MSCN	Fig. 4.a



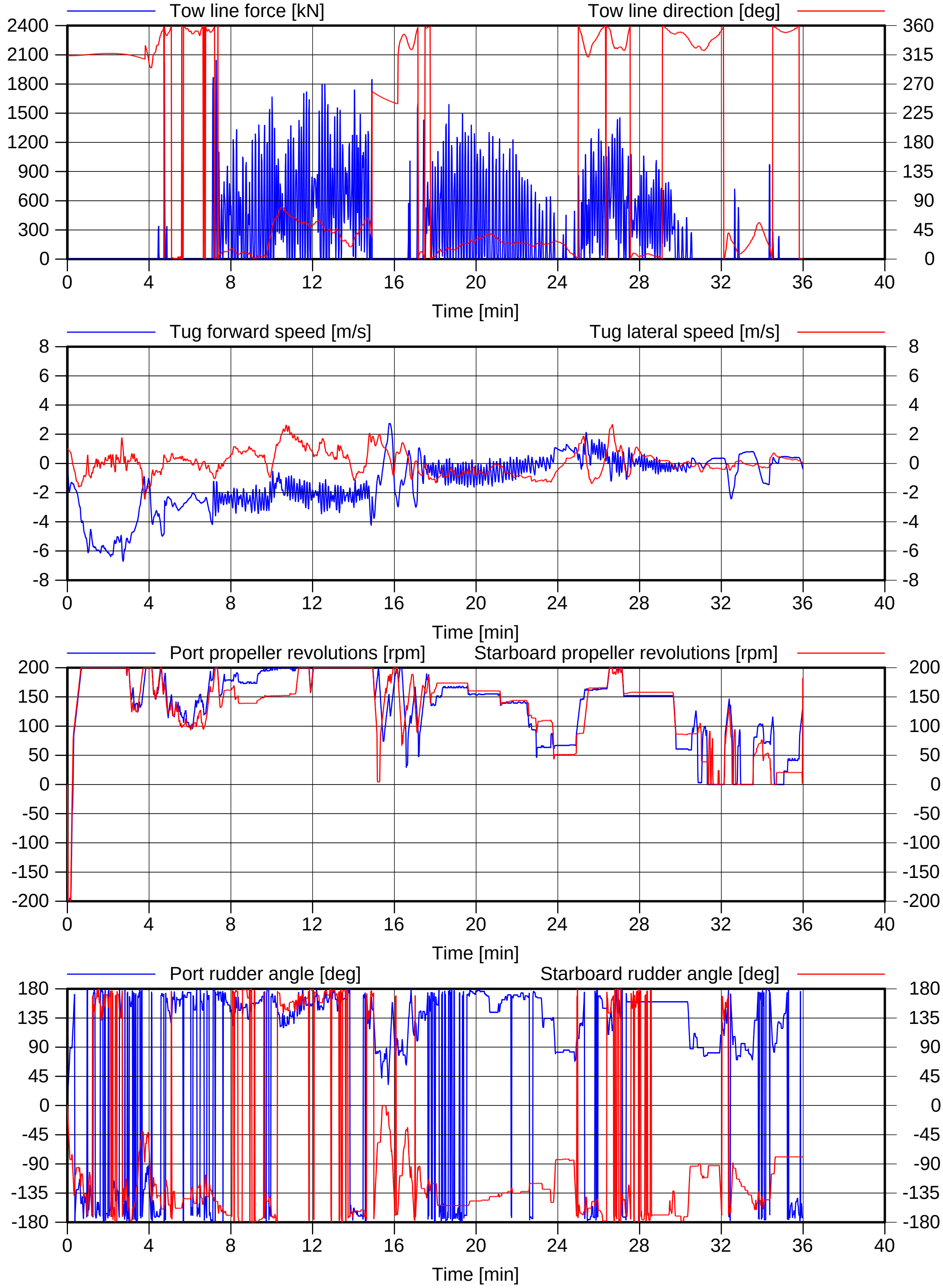
Run: 12	Malta
Arrival	Wind 10m/s from SE
MARIN's Nautical Centre MSCN	Fig. 4.b



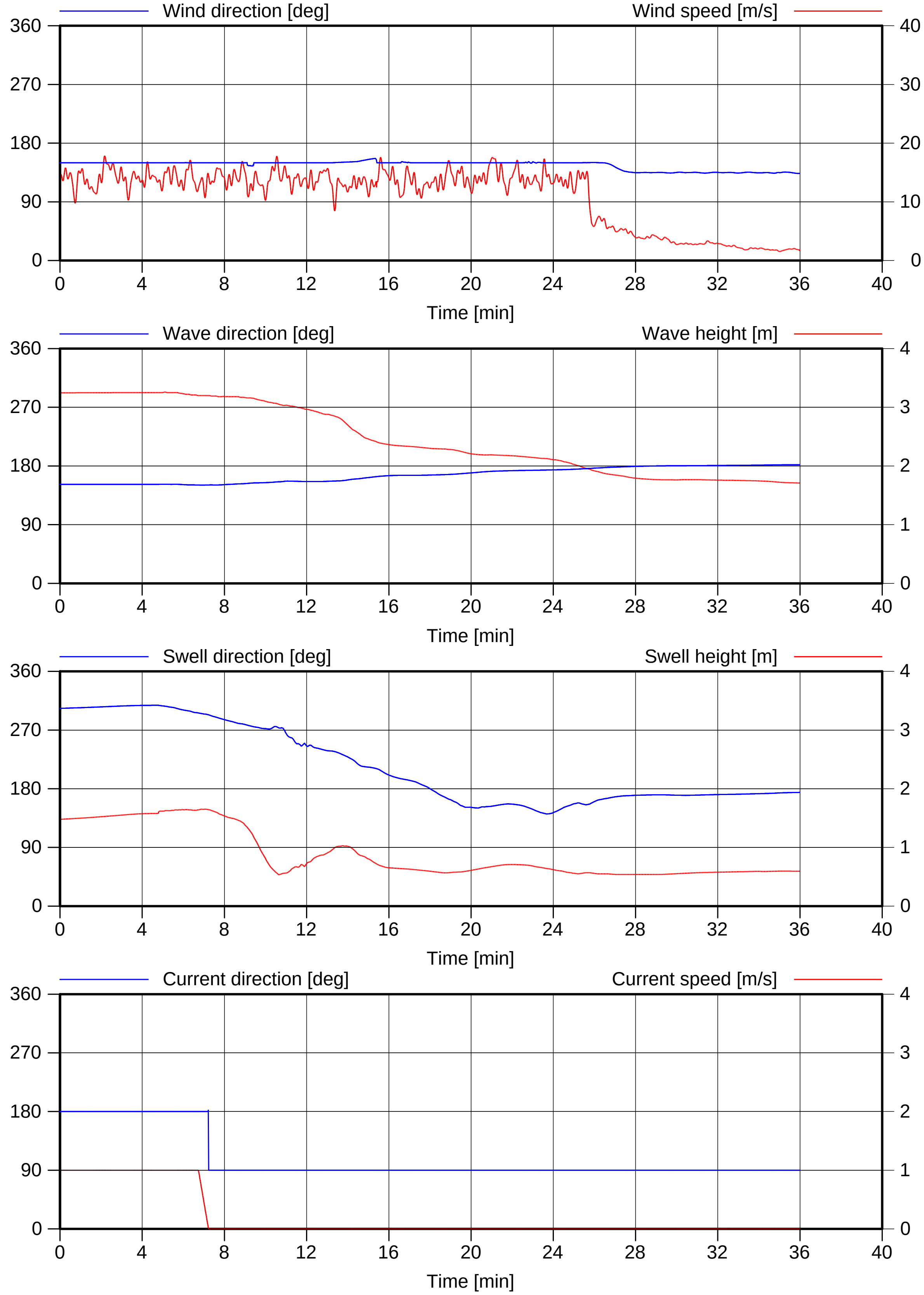
Run: 12	Malta
Arrival	Wind 10m/s from SE
MARIN's Nautical Centre MSCN	Fig. 4.c



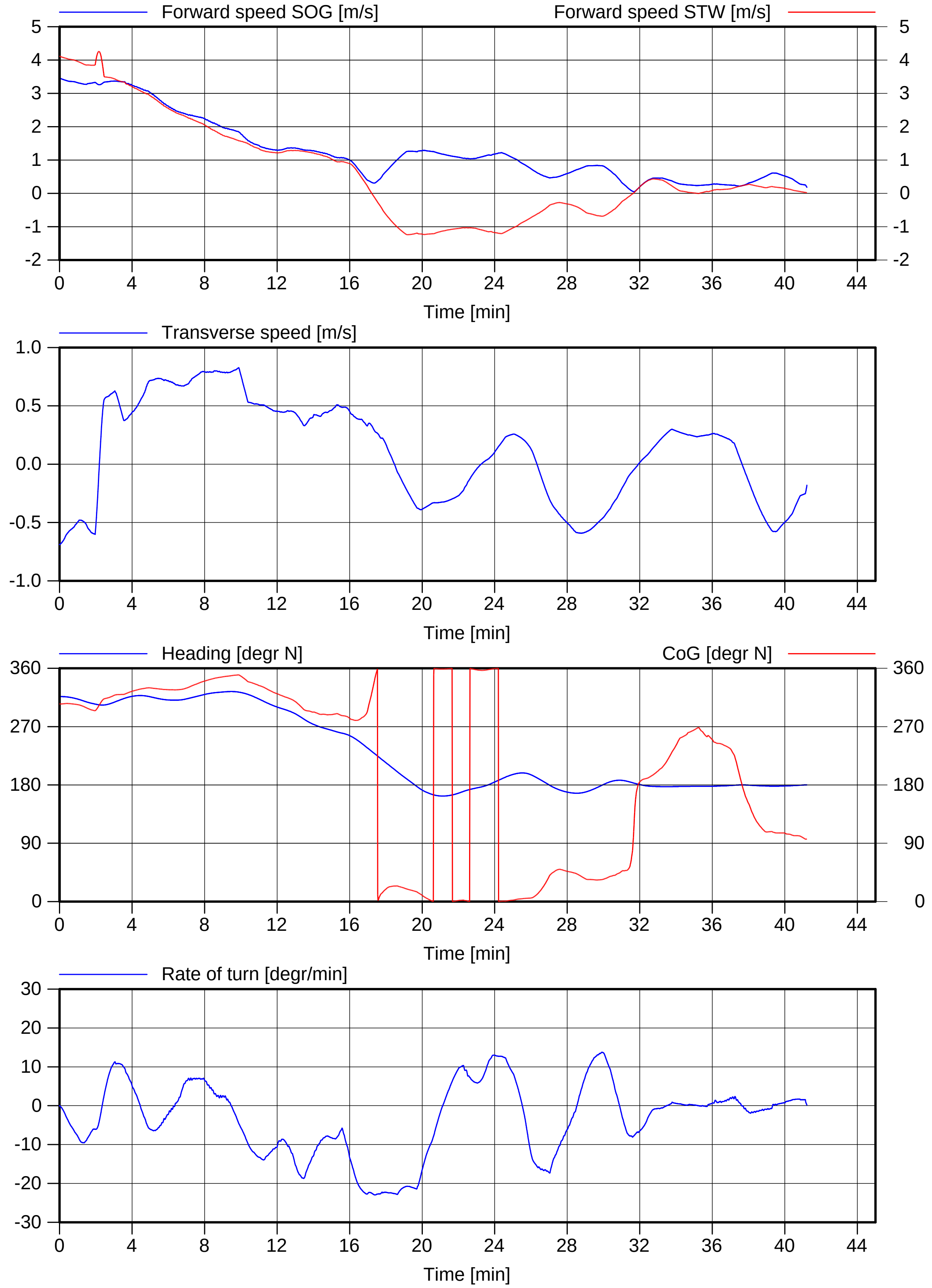
Run: 12	Malta
Arrival	Wind 10m/s from SE
MARIN's Nautical Centre MSCN	Fig. 4.d



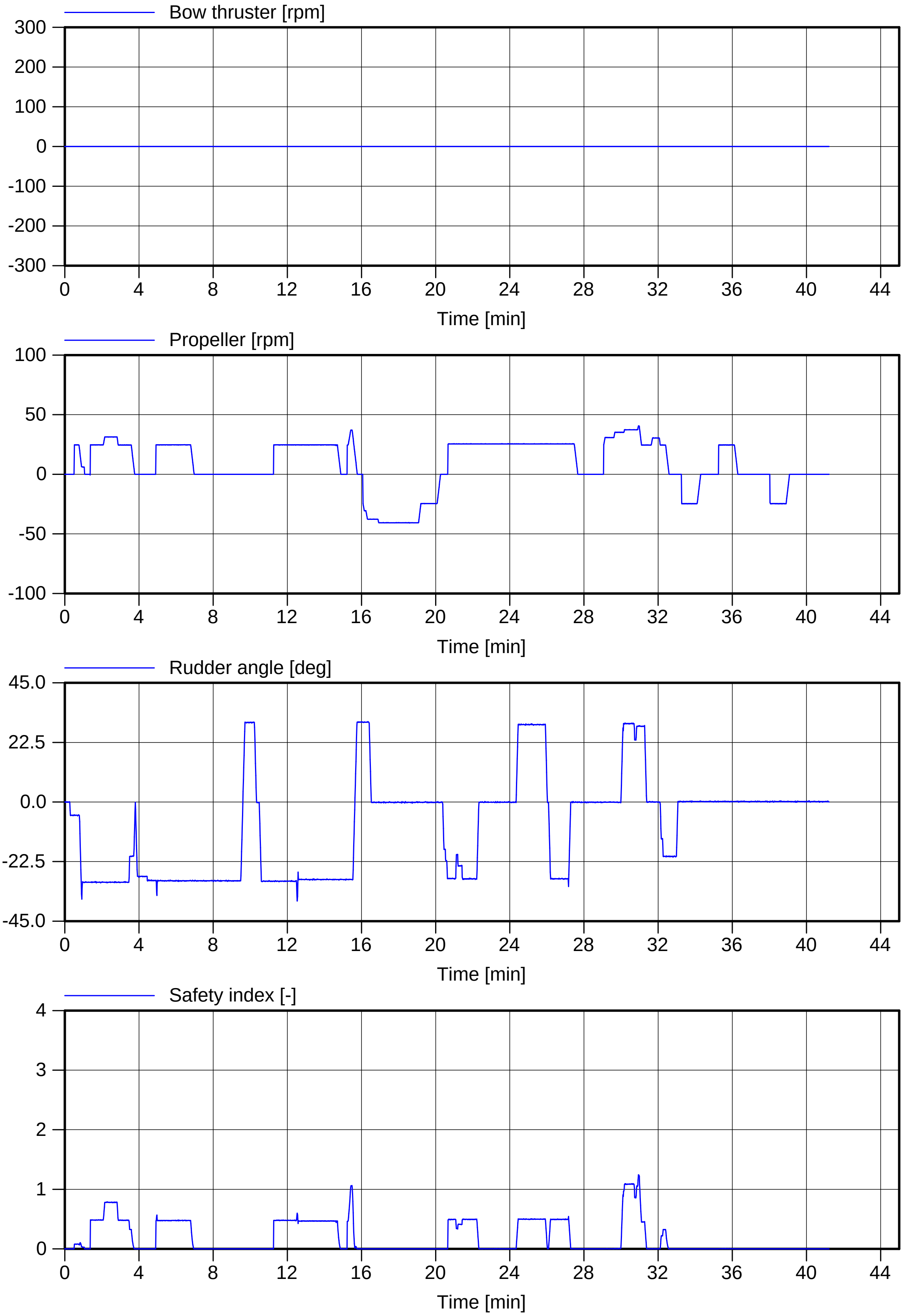
Run: 12	Malta
Arrival	Wind 10m/s from SE
MARIN's Nautical Centre MSCN	Fig. 4.e



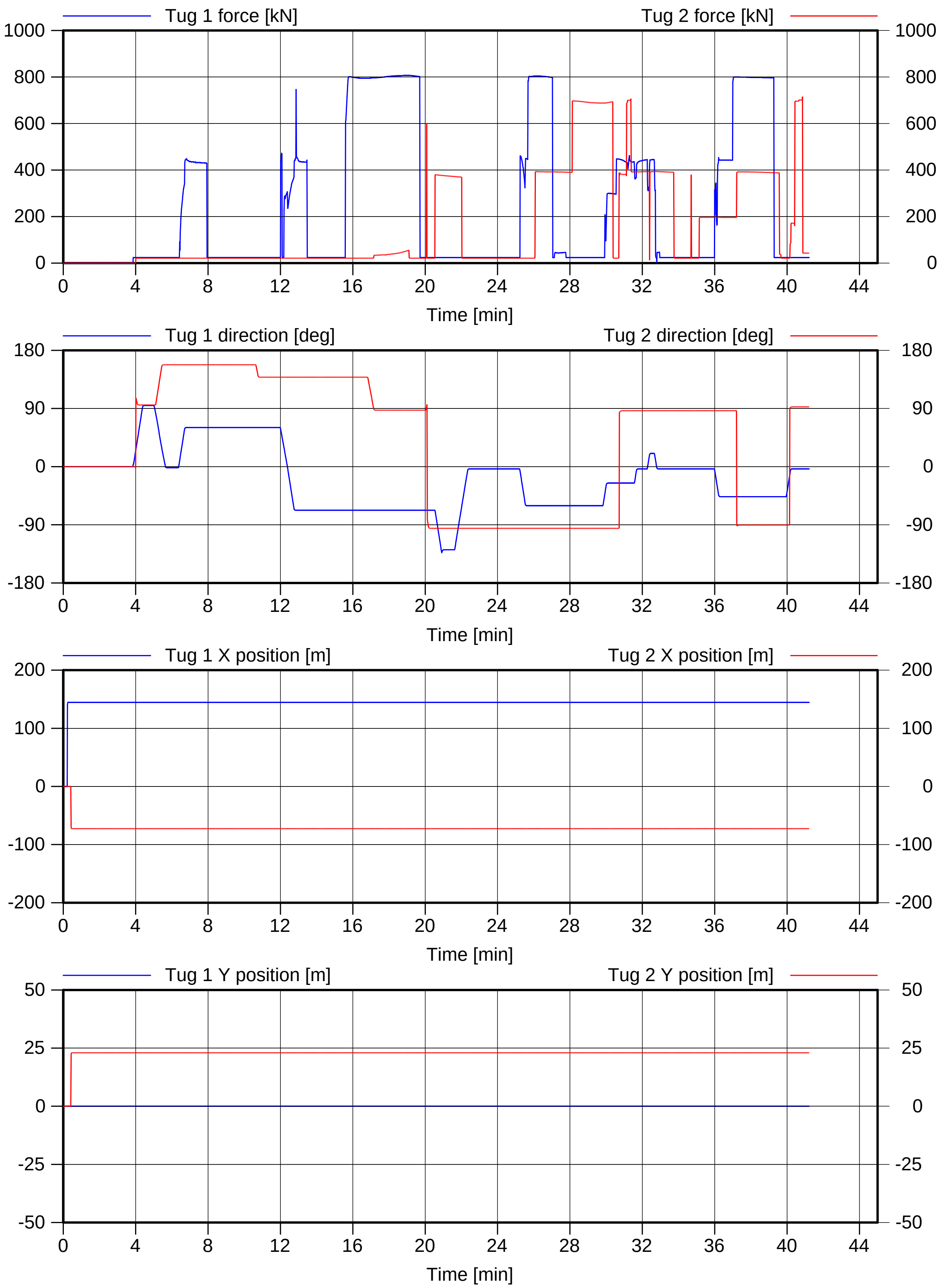
Run: 12	Malta
Arrival	Wind 10m/s from SE
MARIN's Nautical Centre MSCN	Fig. 4.f



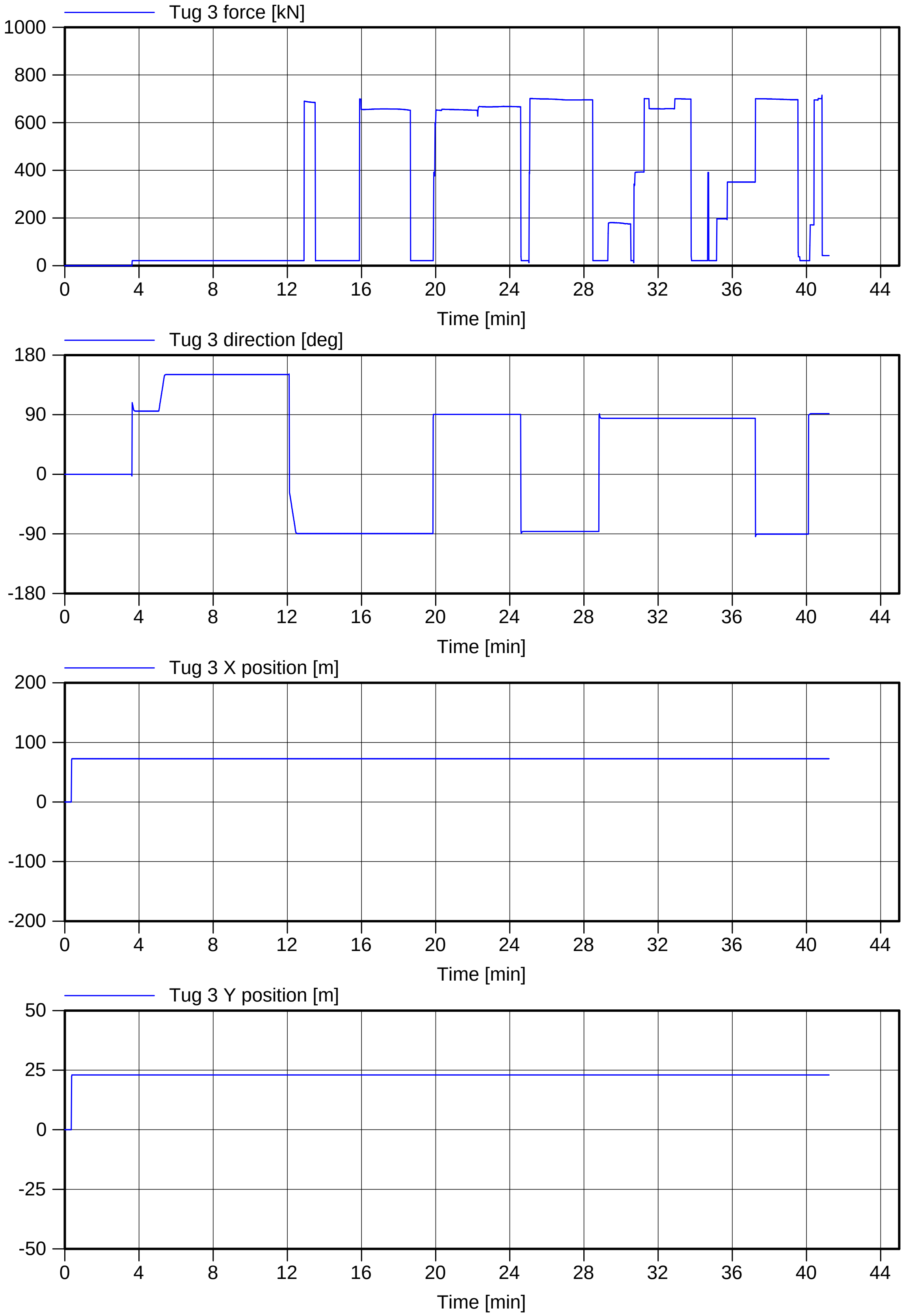
Run: 13	Malta
Arrival	Wind 10m/s from S
MARIN's Nautical Centre MSCN	Fig. 5.a



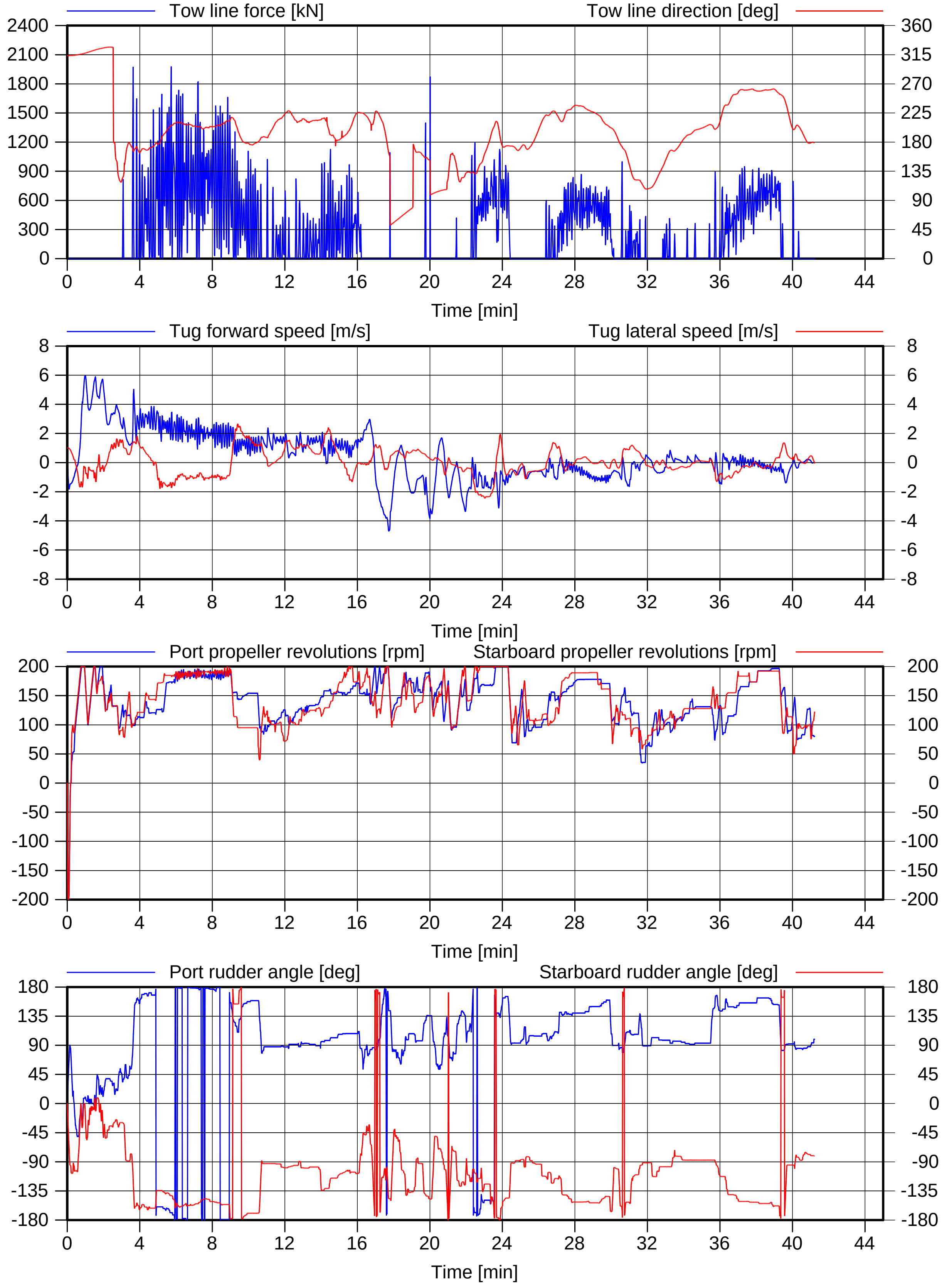
Run: 13	Malta
Arrival	Wind 10m/s from S
MARIN's Nautical Centre MSCN	Fig. 5.b



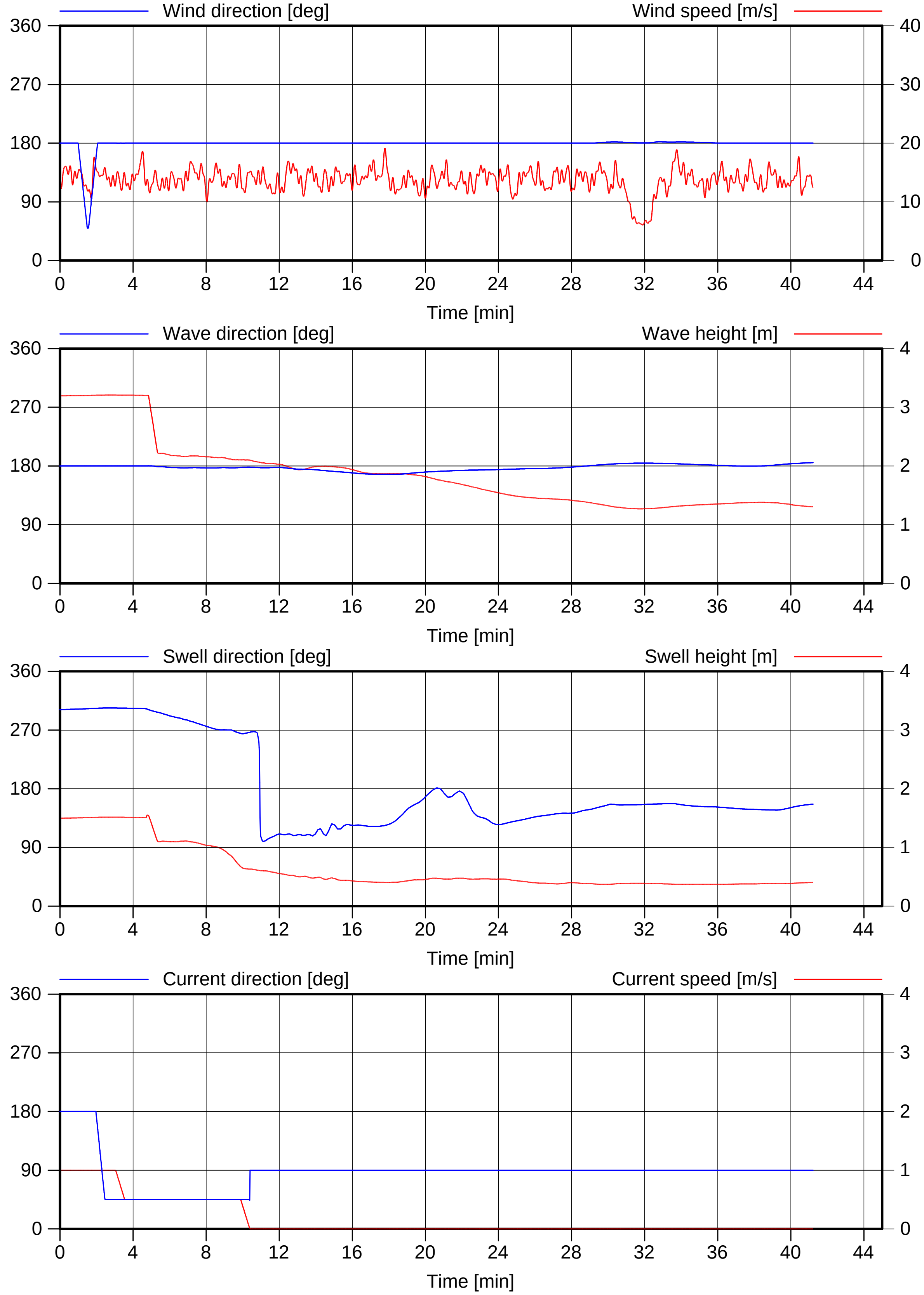
Run: 13	Malta
Arrival	Wind 10m/s from S
MARIN's Nautical Centre MSCN	Fig. 5.c



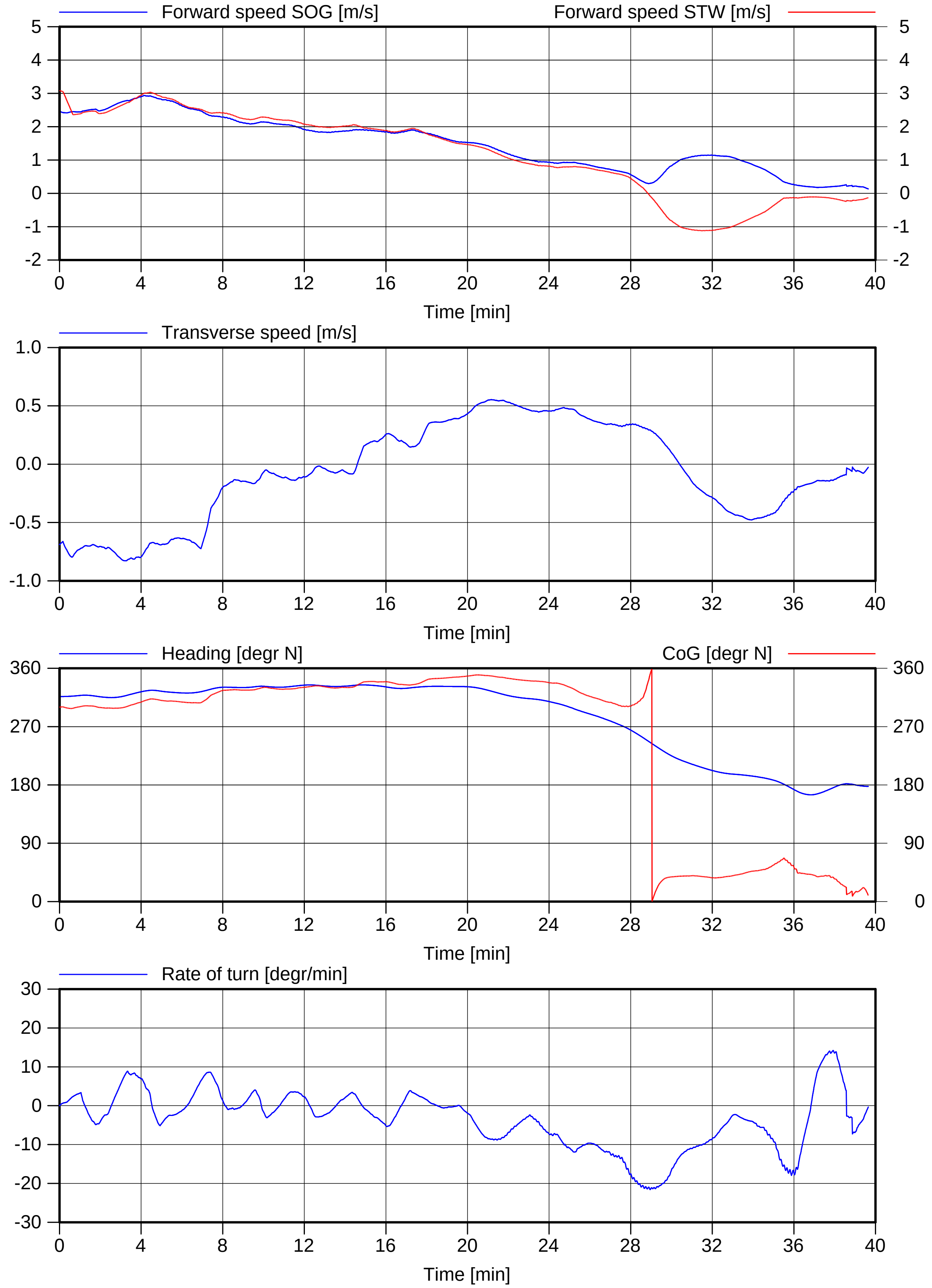
Run: 13	Malta
Arrival	Wind 10m/s from S
MARIN's Nautical Centre MSCN	Fig. 5.d



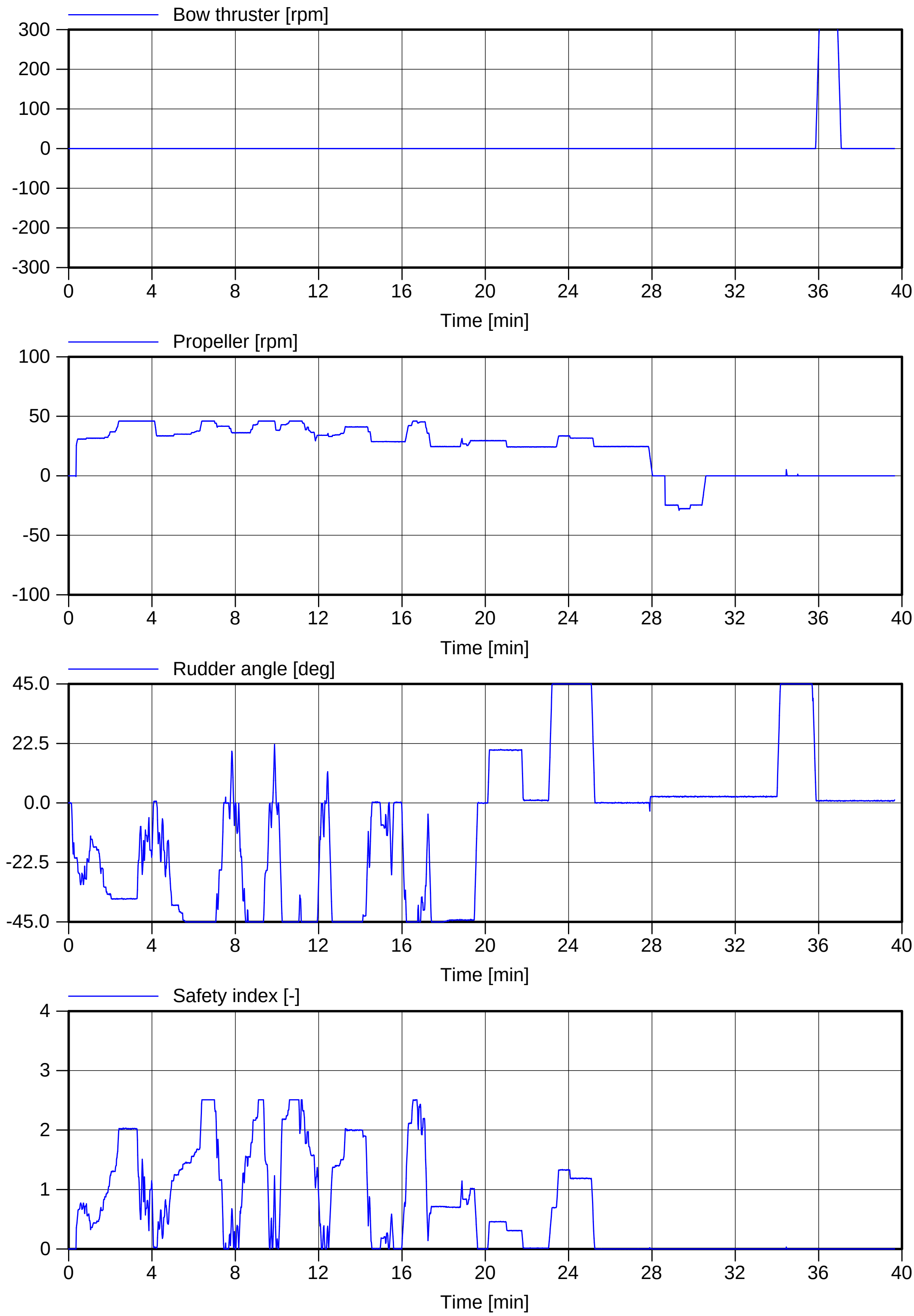
Run: 13	Malta
Arrival	Wind 10m/s from S
MARIN's Nautical Centre MSCN	Fig. 5.e



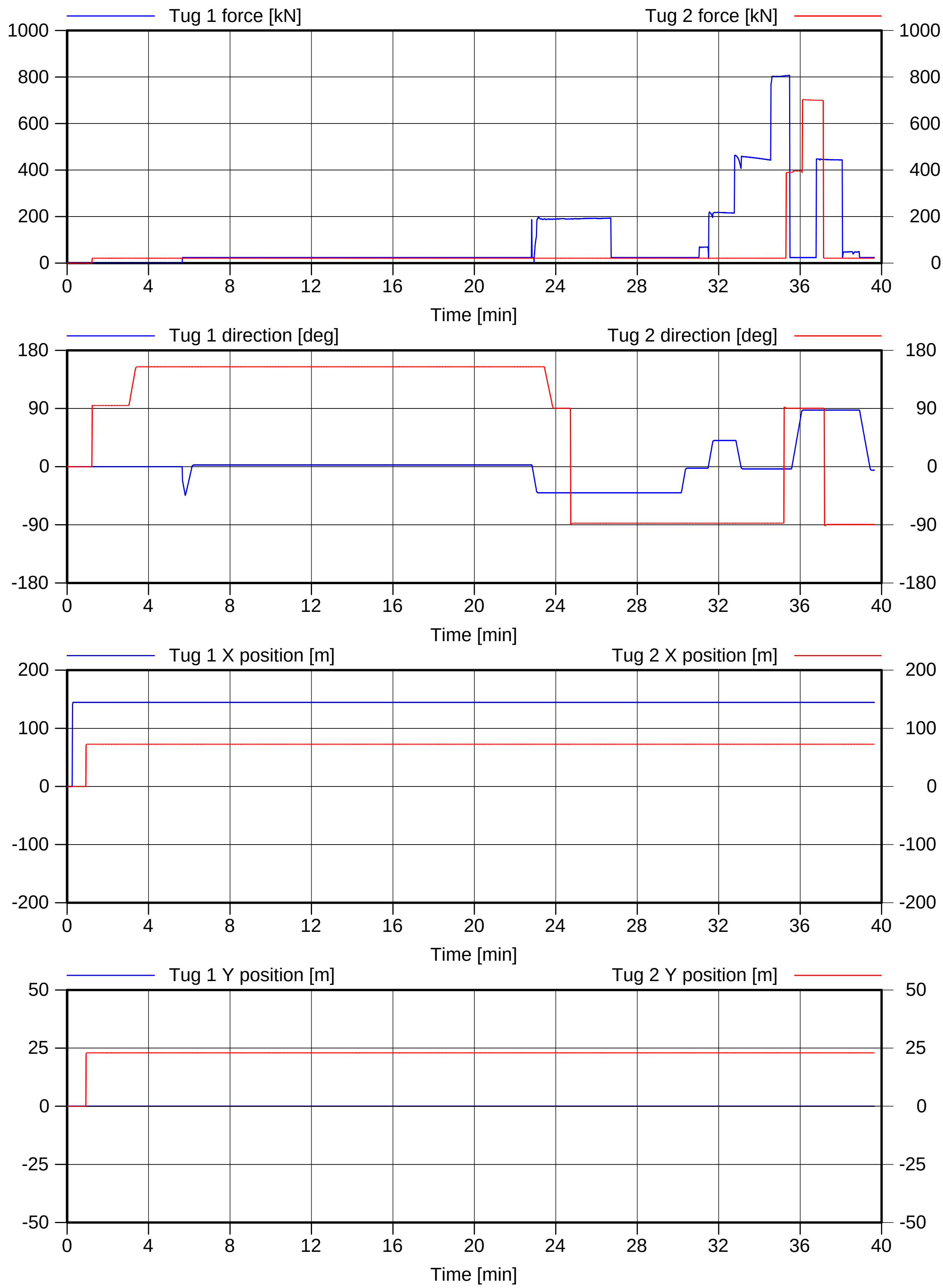
Run: 13	Malta
Arrival	Wind 10m/s from S
MARIN's Nautical Centre MSCN	Fig. 5.f



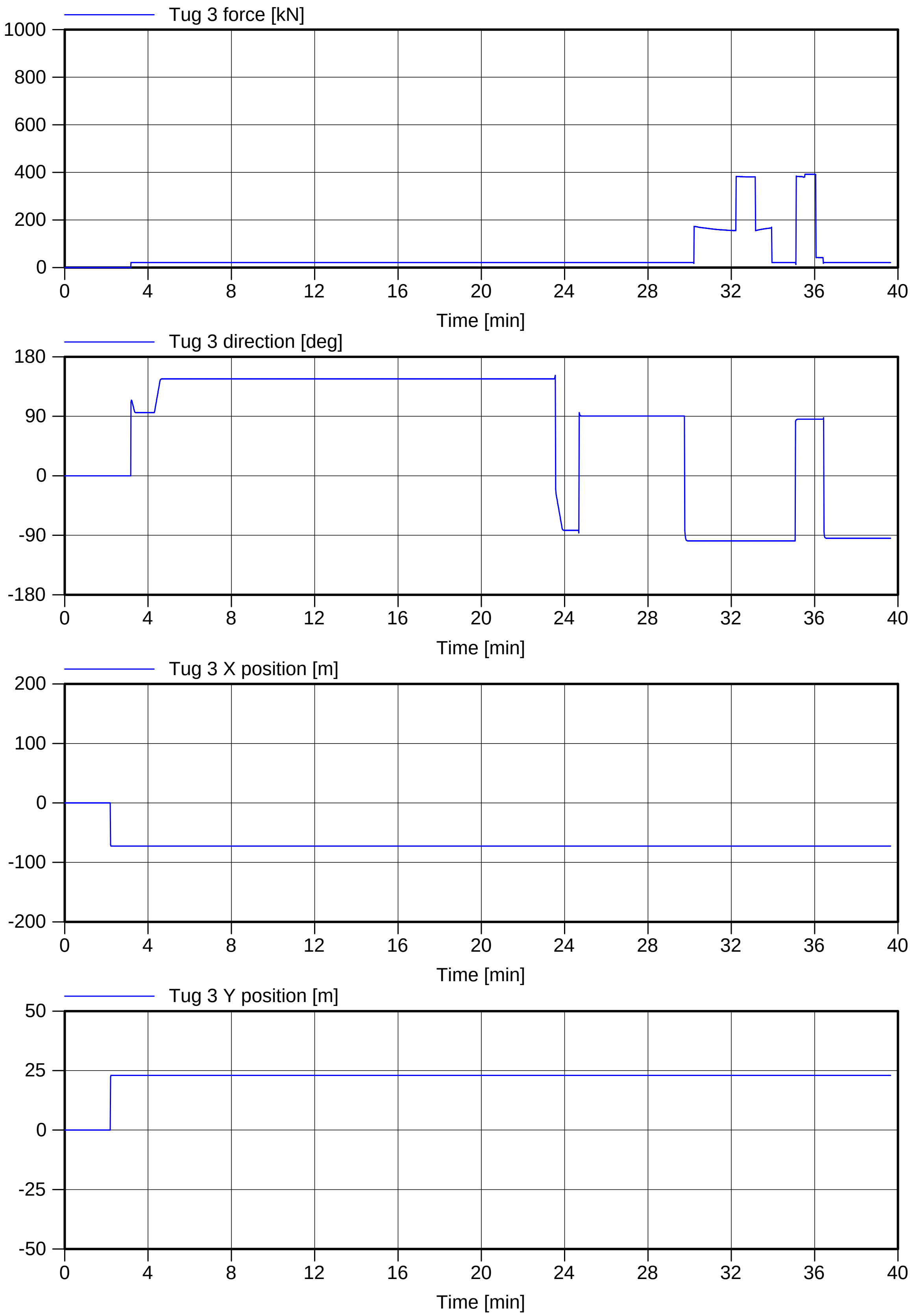
Run: 15	Malta
Arrival	Wind 14m/s from W
MARIN's Nautical Centre MSCN	Fig. 6.a



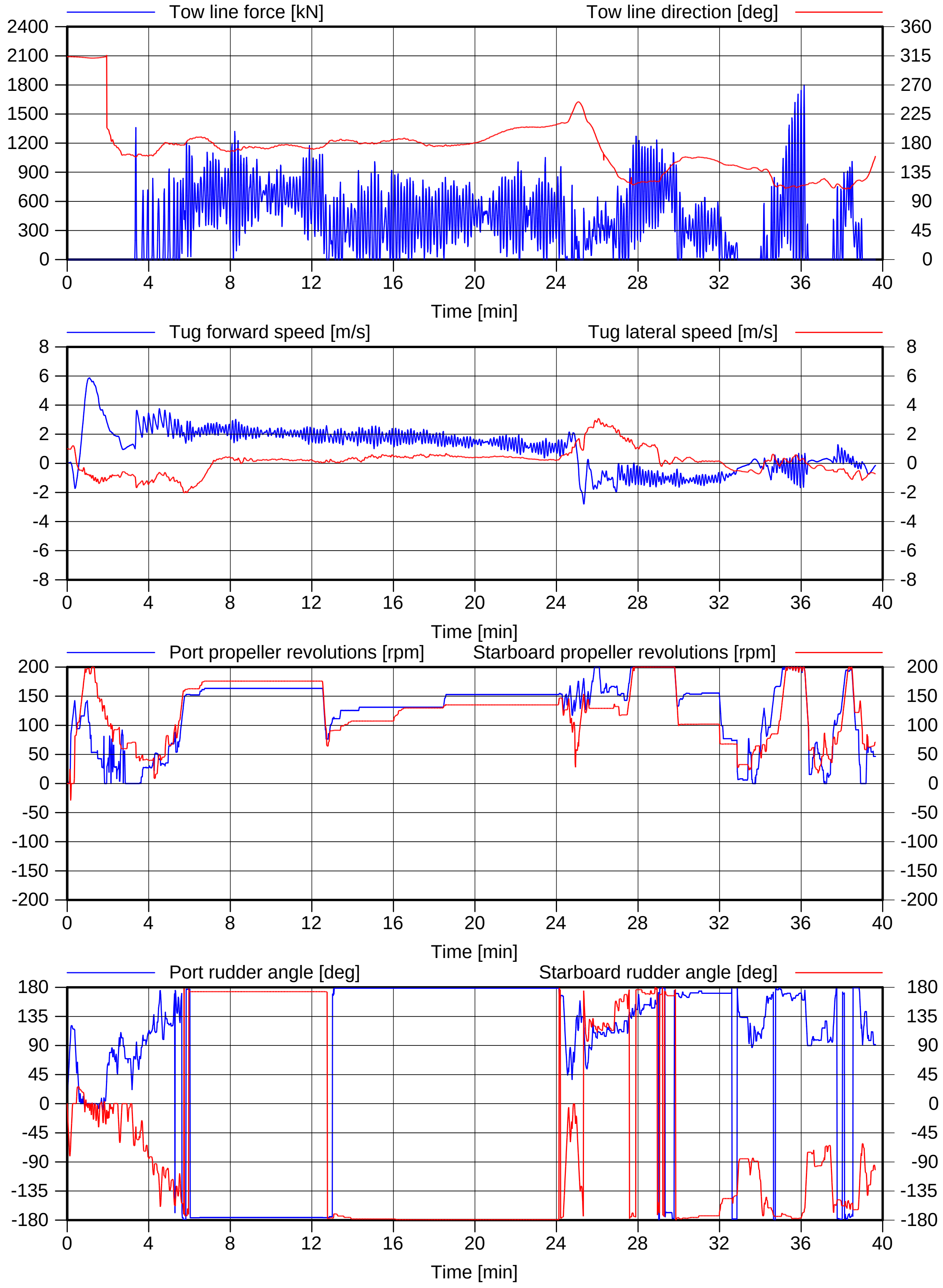
Run: 15	Malta
Arrival	Wind 14m/s from W
MARIN's Nautical Centre MSCN	Fig. 6.b



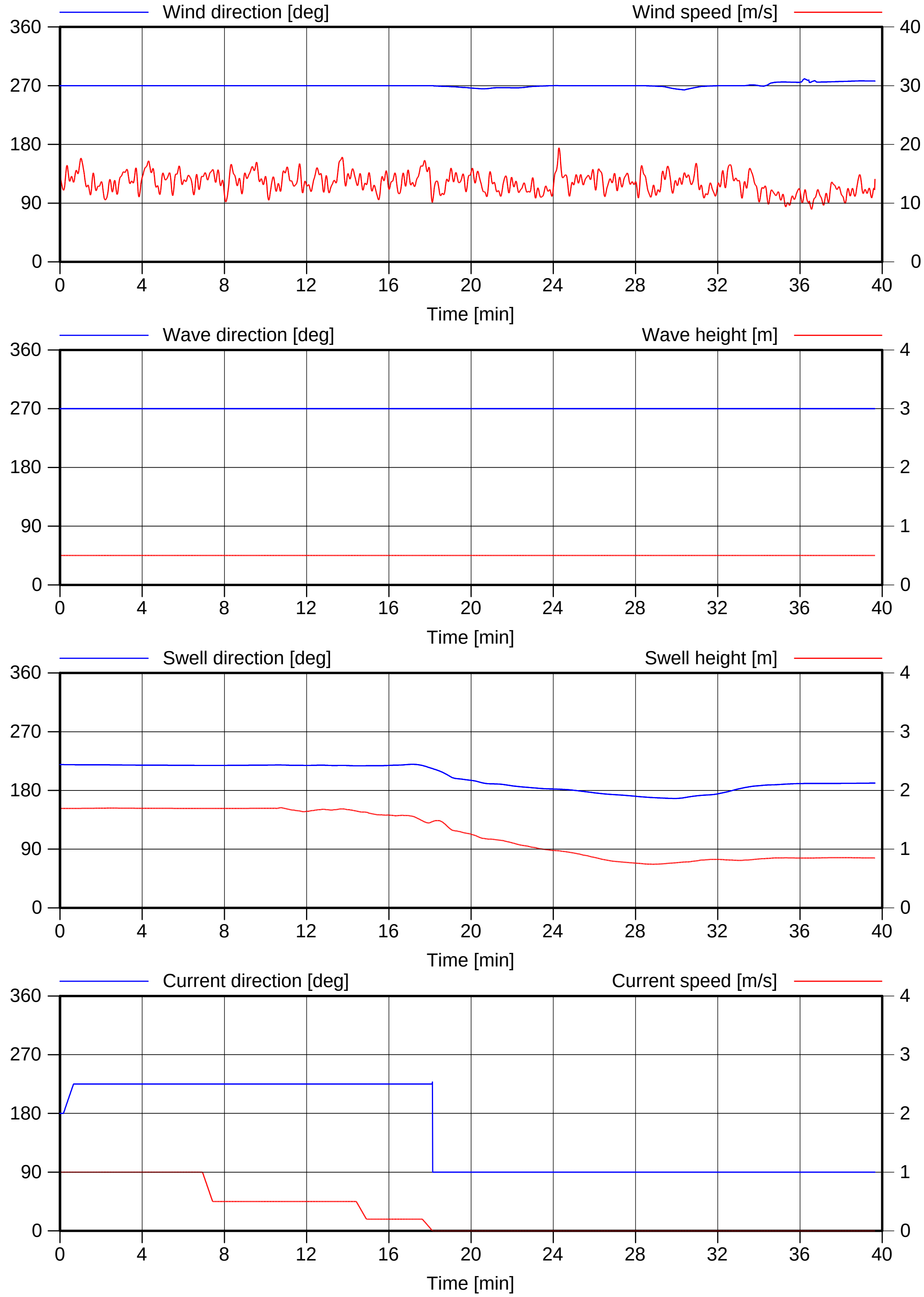
Run: 15	Malta
Arrival	Wind 14m/s from W
MARIN's Nautical Centre MSCN	Fig. 6.c



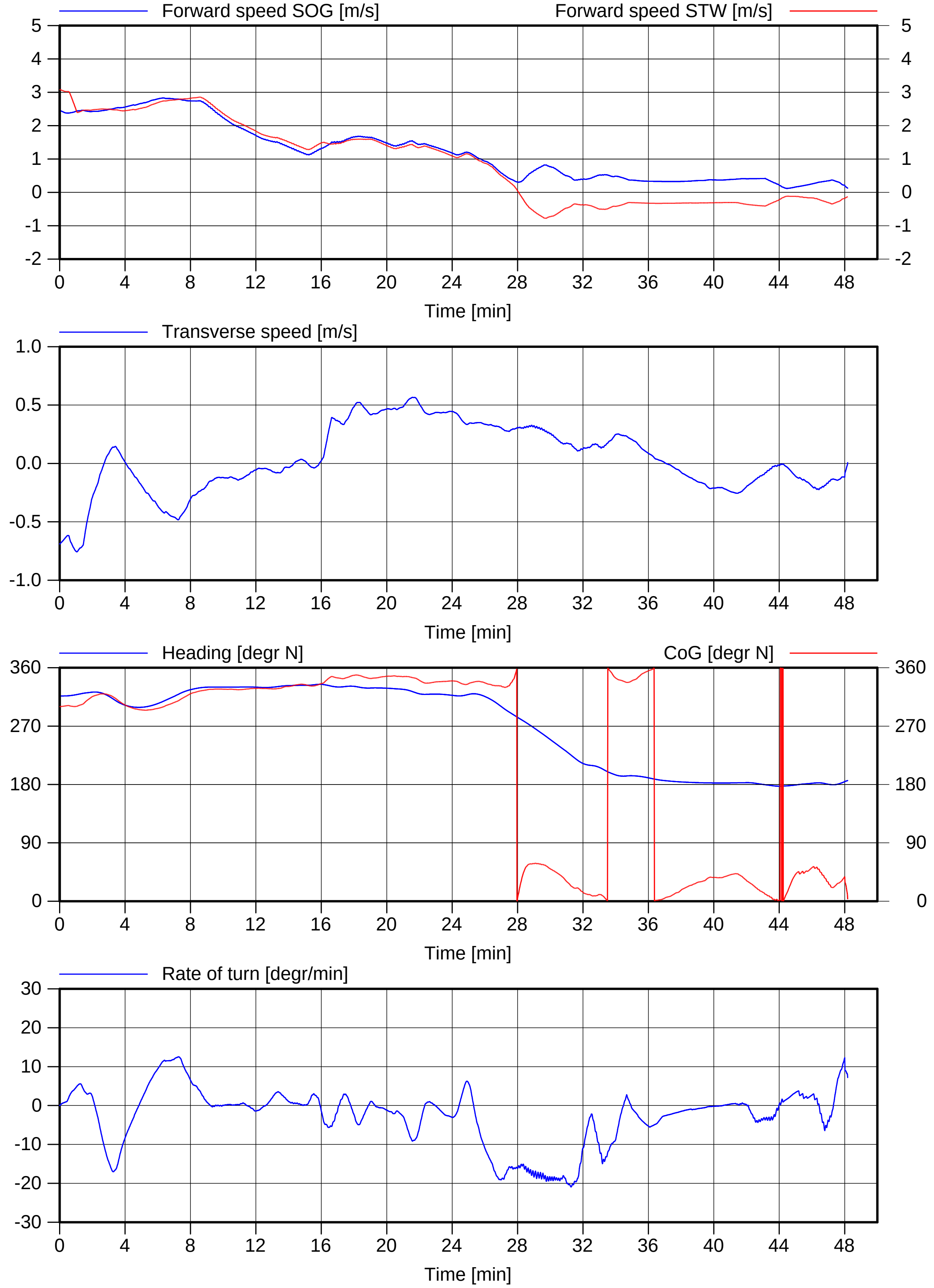
Run: 15	Malta
Arrival	Wind 14m/s from W
MARIN's Nautical Centre MSCN	Fig. 6.d



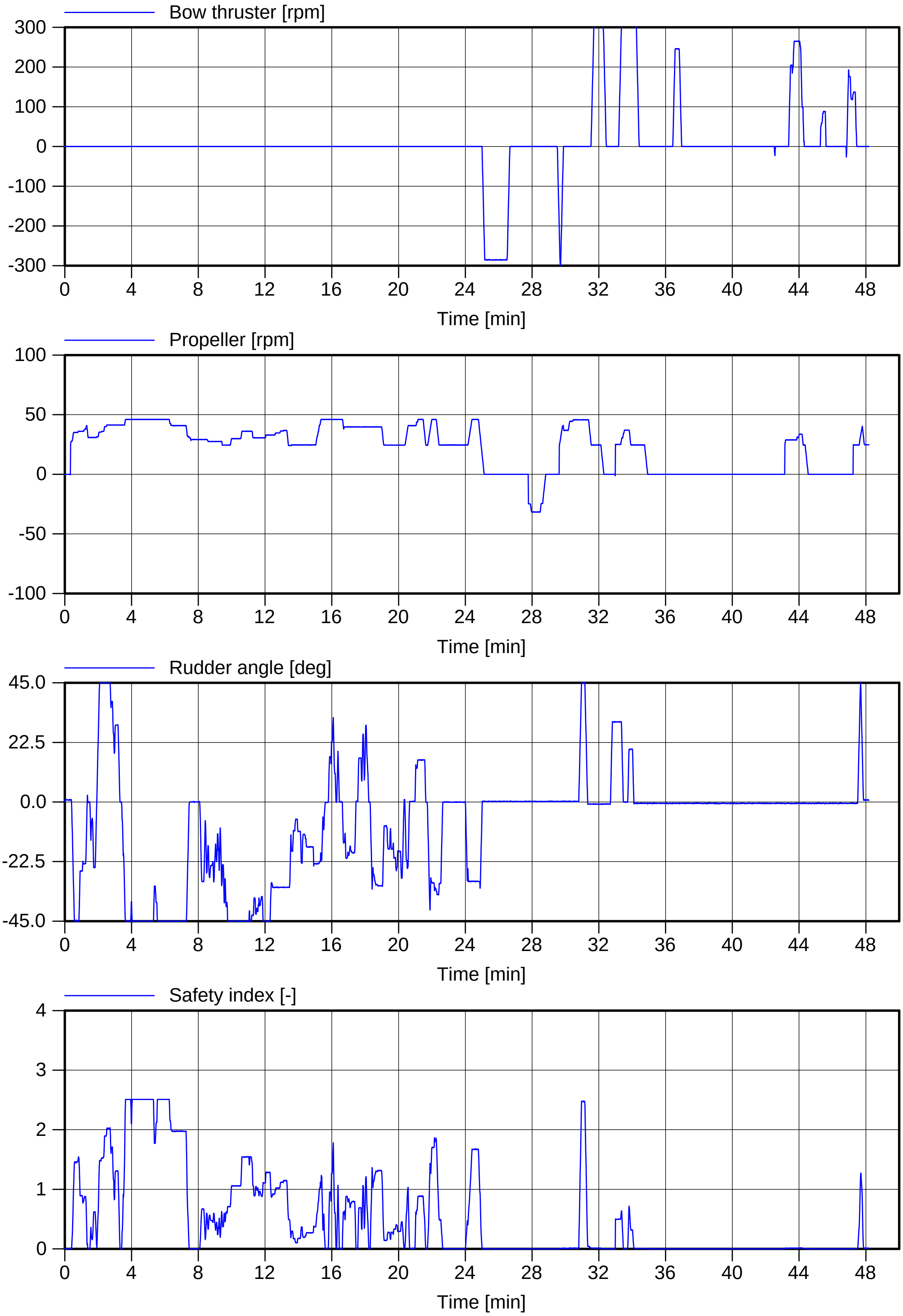
Run: 15	Malta
Arrival	Wind 14m/s from W
MARIN's Nautical Centre MSCN	Fig. 6.e



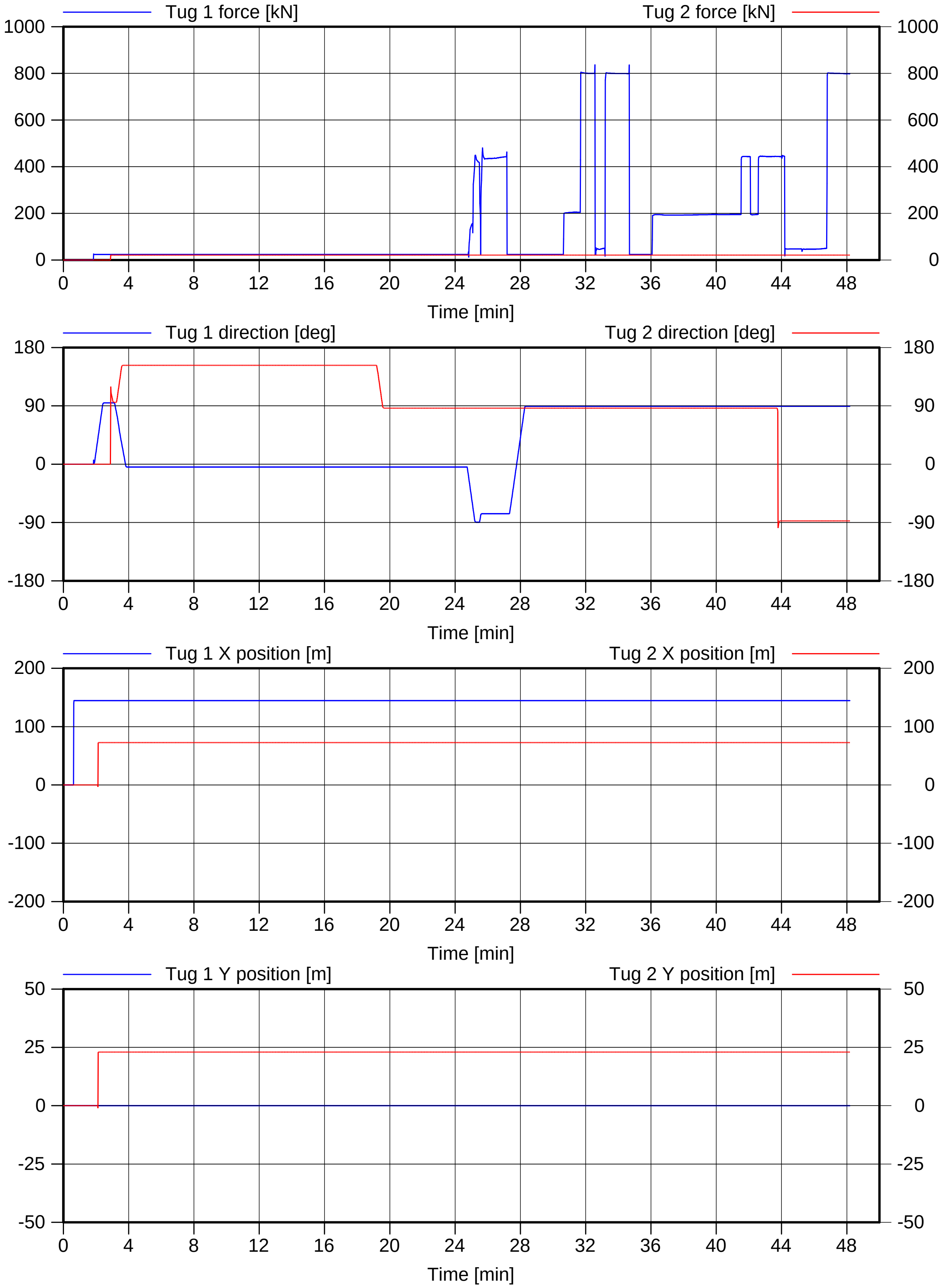
Run: 15	Malta
Arrival	Wind 14m/s from W
MARIN's Nautical Centre MSCN	Fig. 6.f



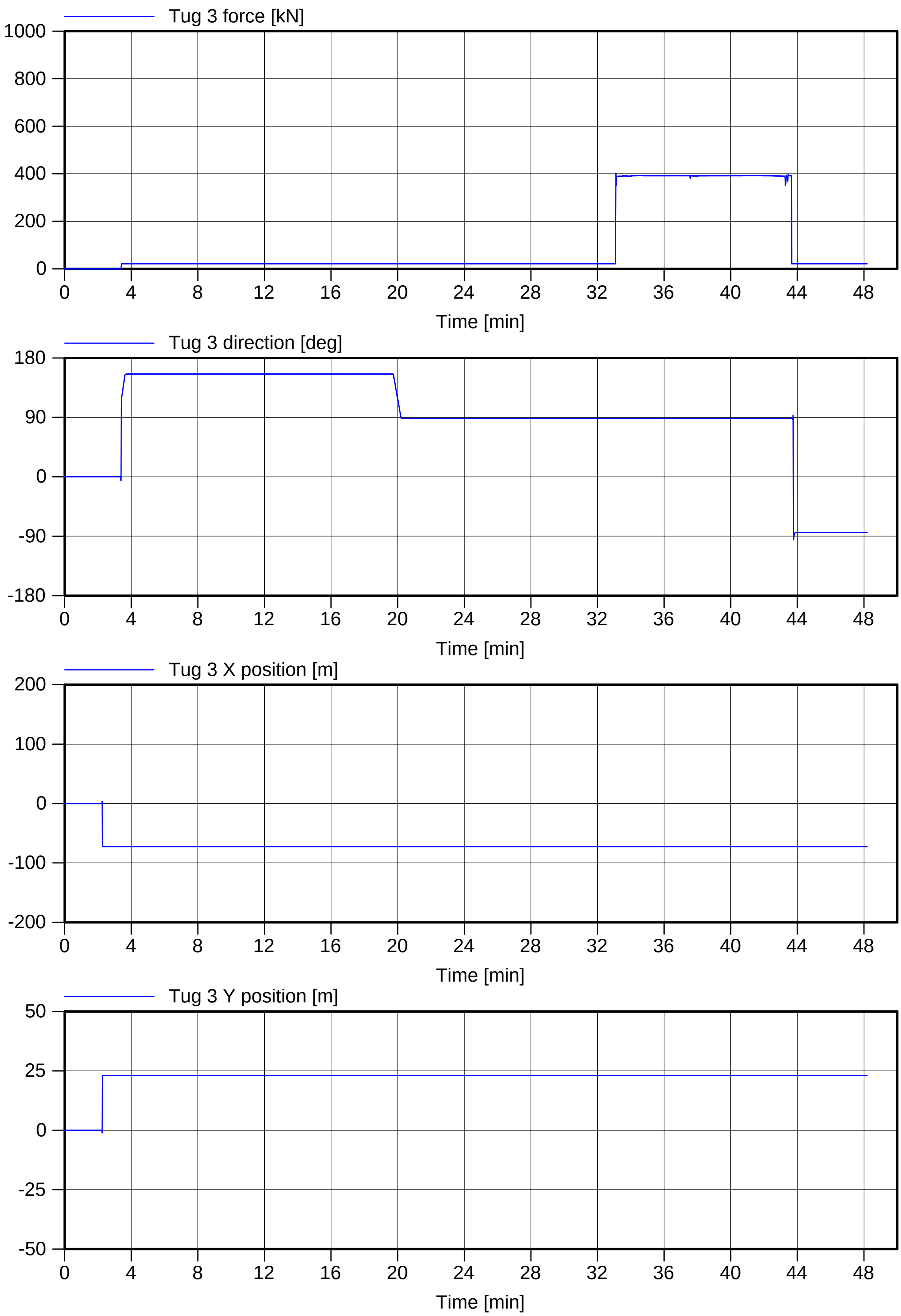
Run: 16	Malta
Arrival	Wind 14m/s from W
MARIN's Nautical Centre MSCN	Fig. 7.a



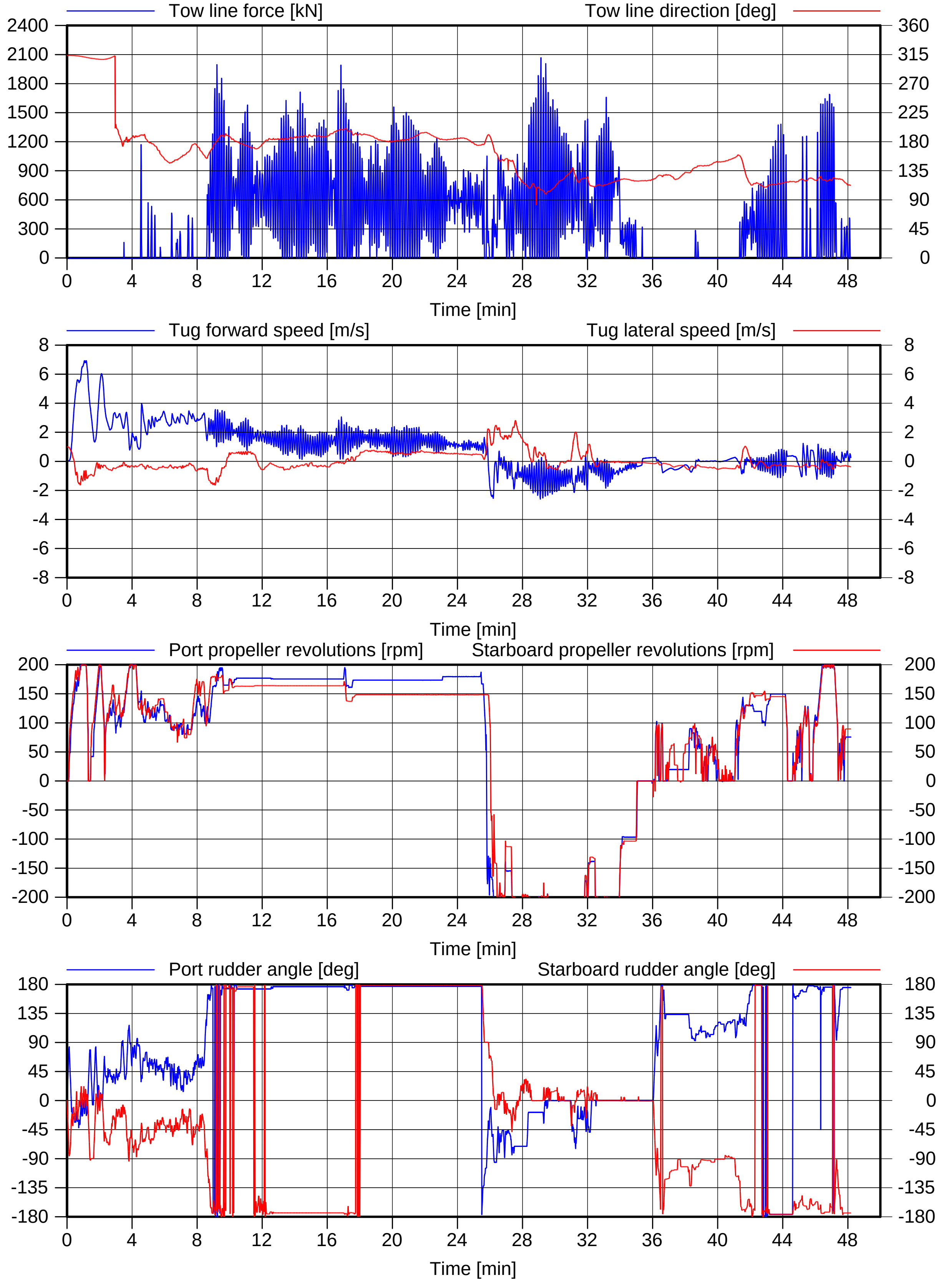
Run: 16	Malta
Arrival	Wind 14m/s from W
MARIN's Nautical Centre MSCN	Fig. 7.b



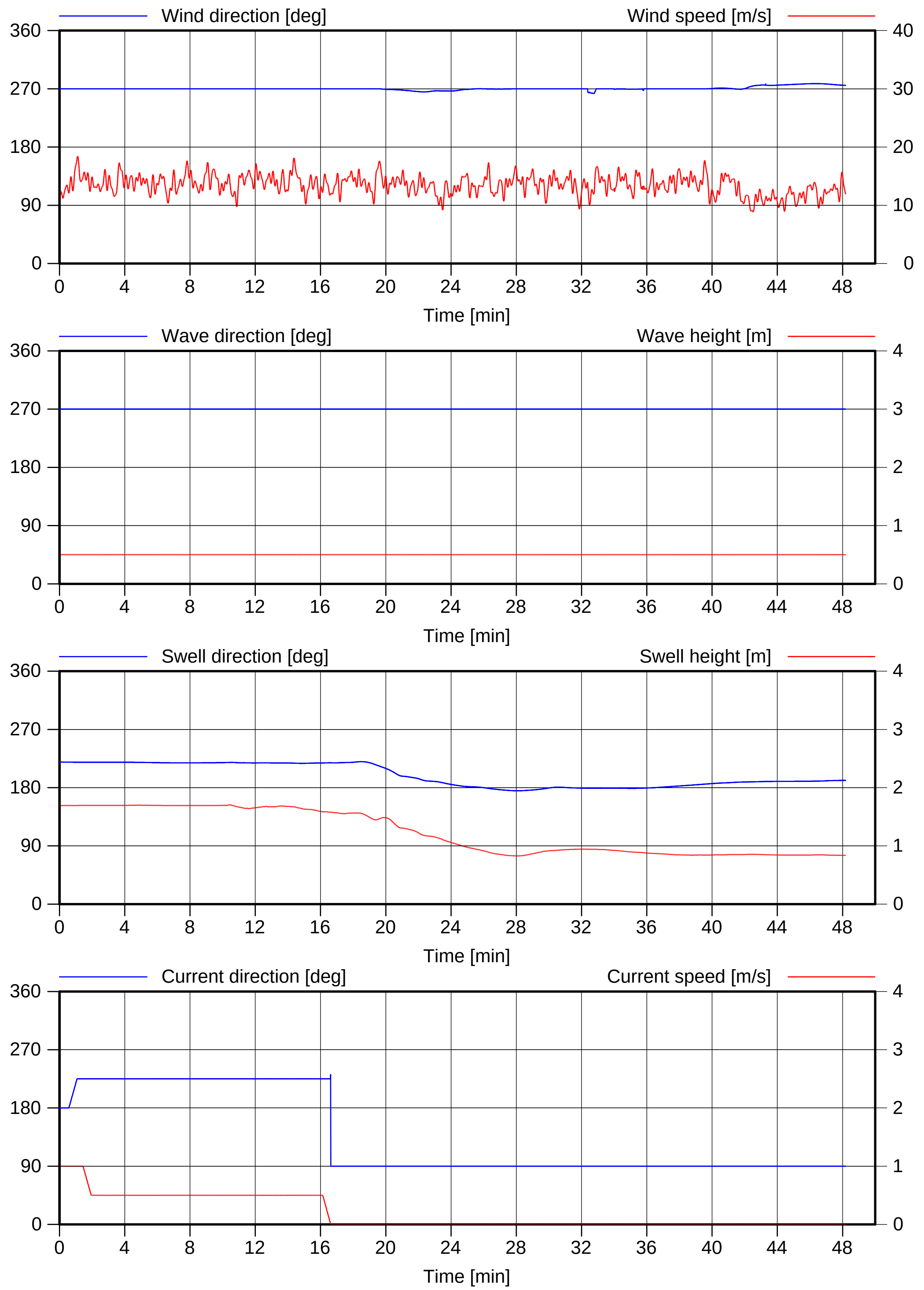
Run: 16	Malta
Arrival	Wind 14m/s from W
MARIN's Nautical Centre MSCN	Fig. 7.c



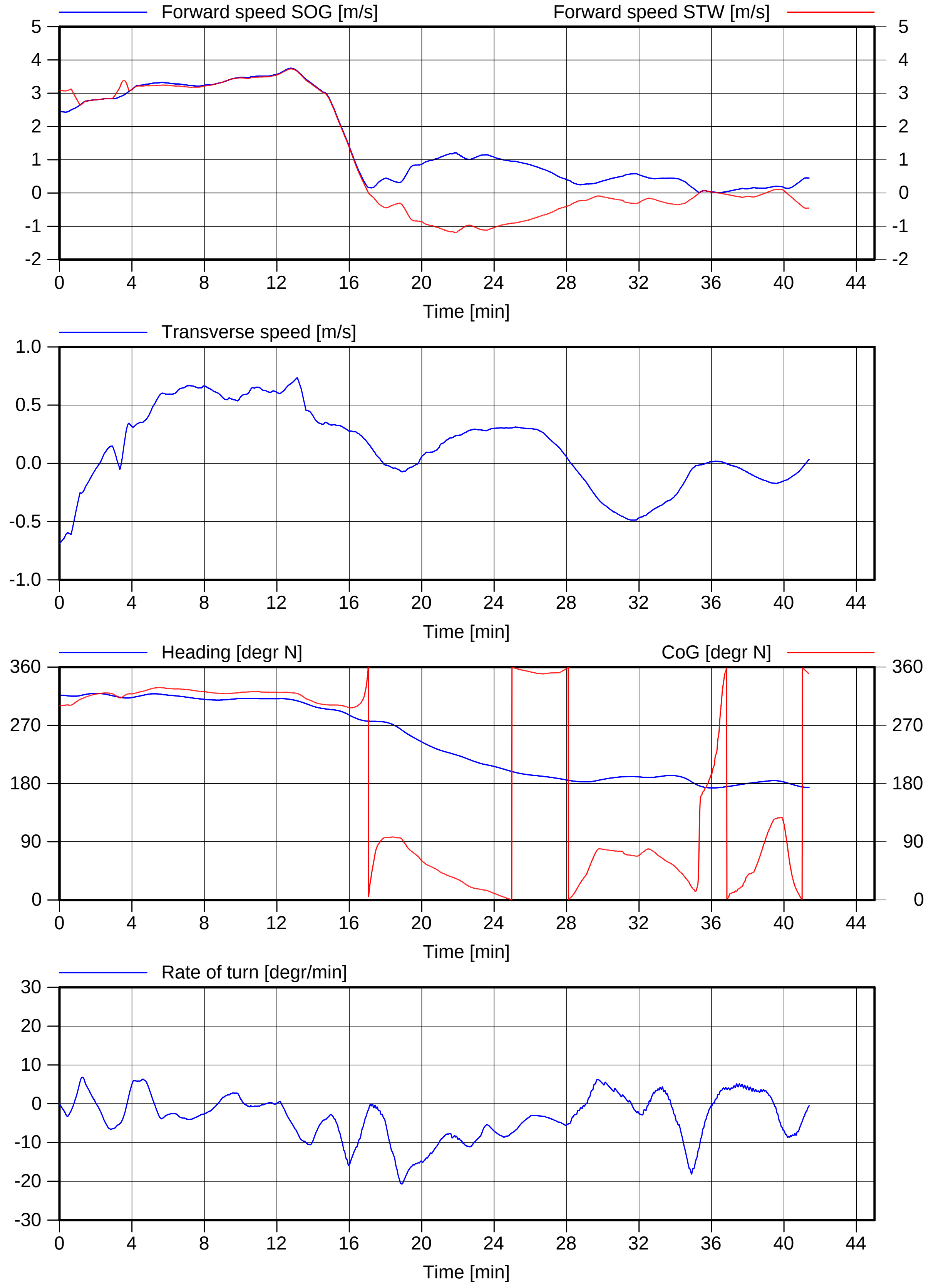
Run: 16	Malta
Arrival	Wind 14m/s from W
MARIN's Nautical Centre MSCN	Fig. 7.d



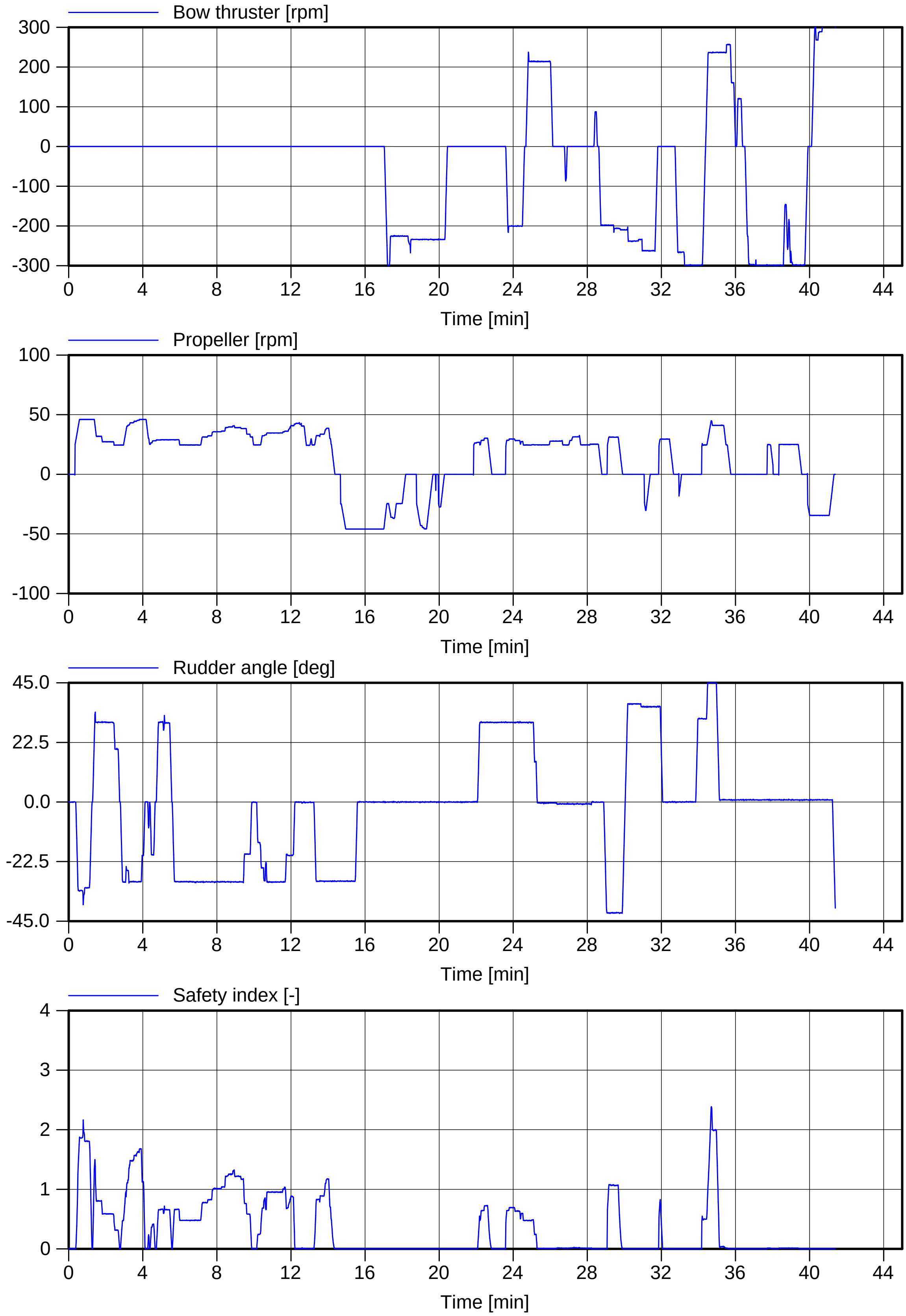
Run: 16	Malta
Arrival	Wind 14m/s from W
MARIN's Nautical Centre MSCN	Fig. 7.e



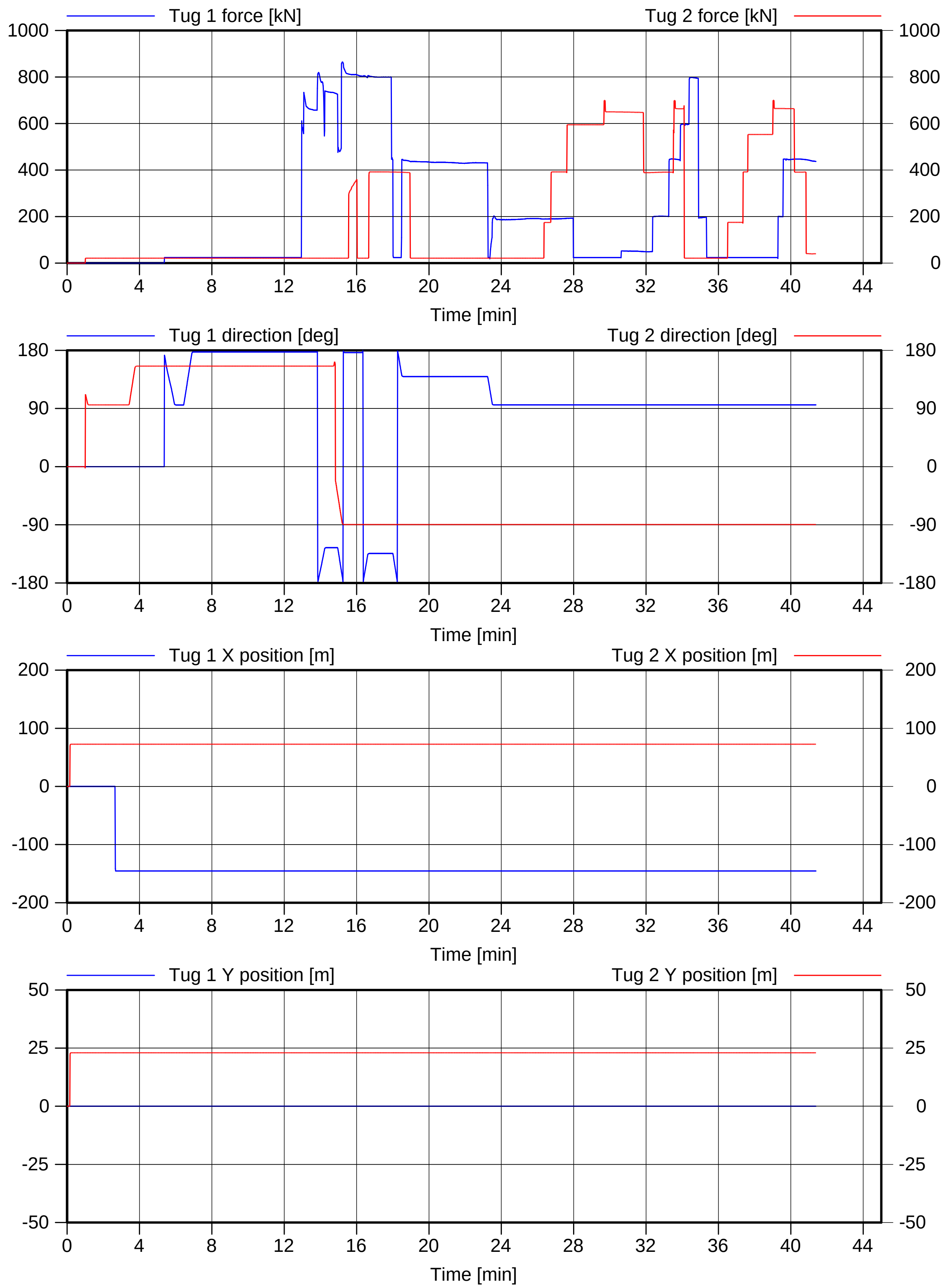
Run: 16	Malta
Arrival	Wind 14m/s from W
MARIN's Nautical Centre MSCN	Fig. 7.f



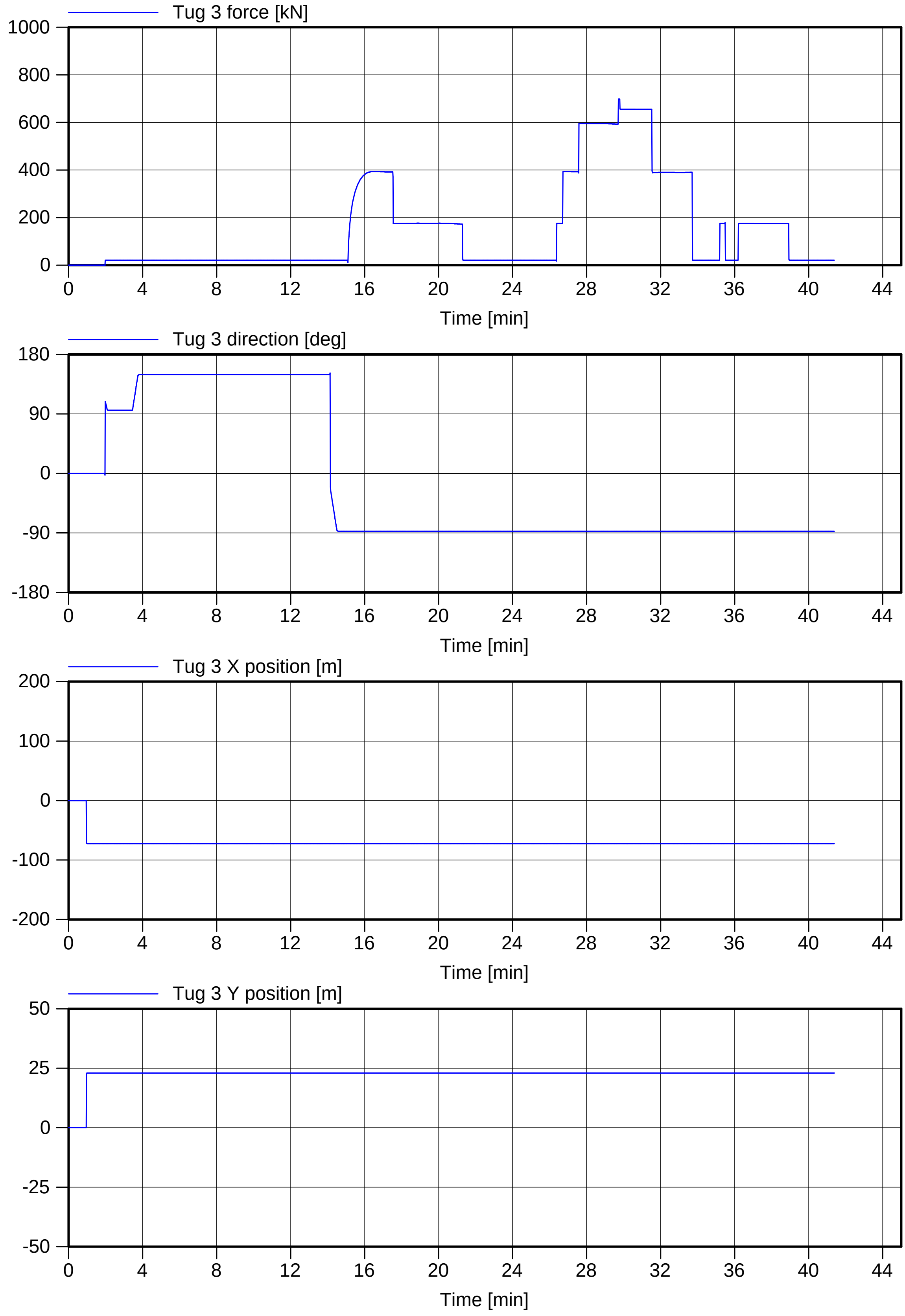
Run: 17	Malta
Arrival	Wind 12m/s from S
MARIN's Nautical Centre MSCN	Fig. 8.a



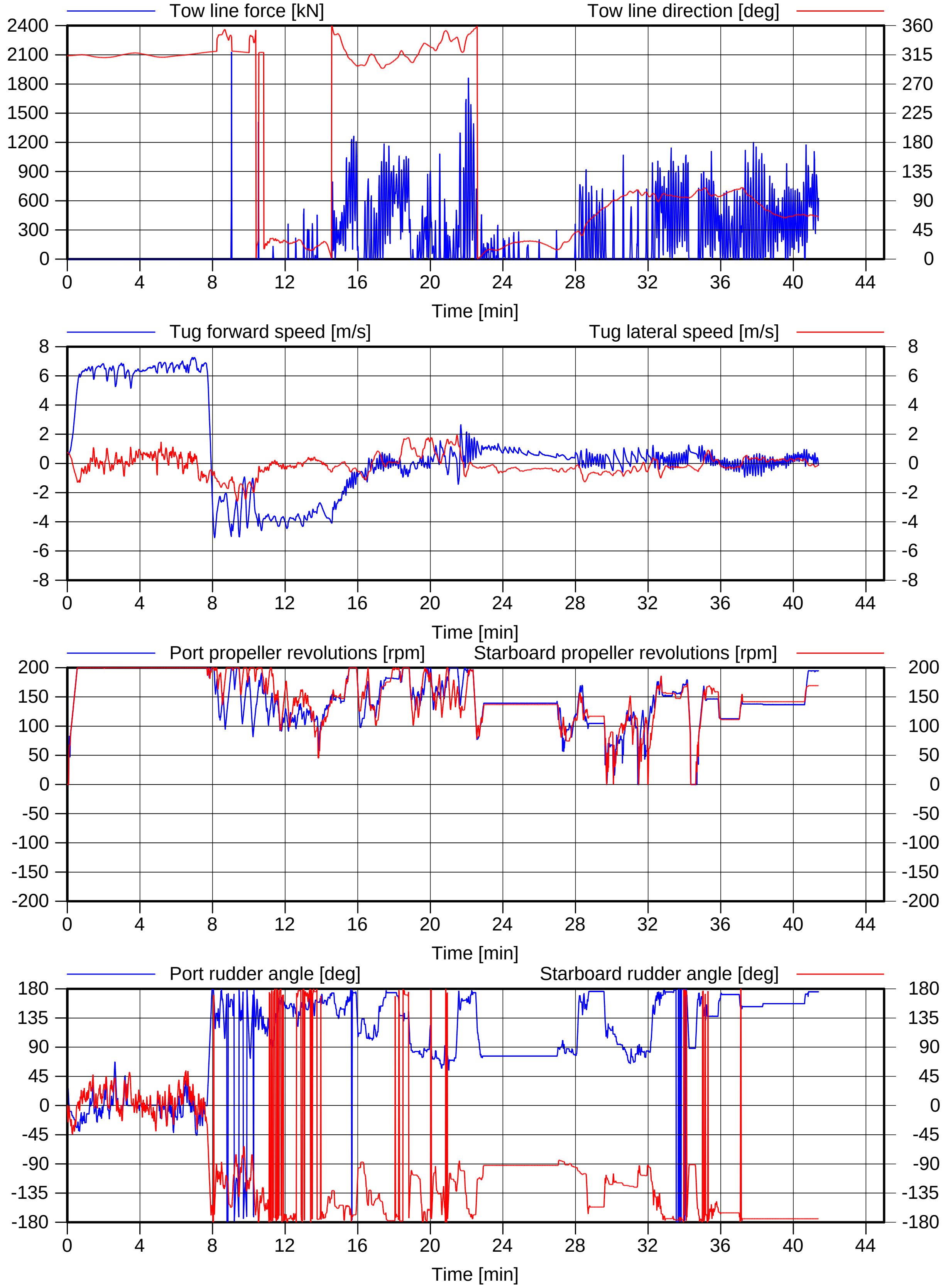
Run: 17	Malta
Arrival	Wind 12m/s from S
MARIN's Nautical Centre MSCN	Fig. 8.b



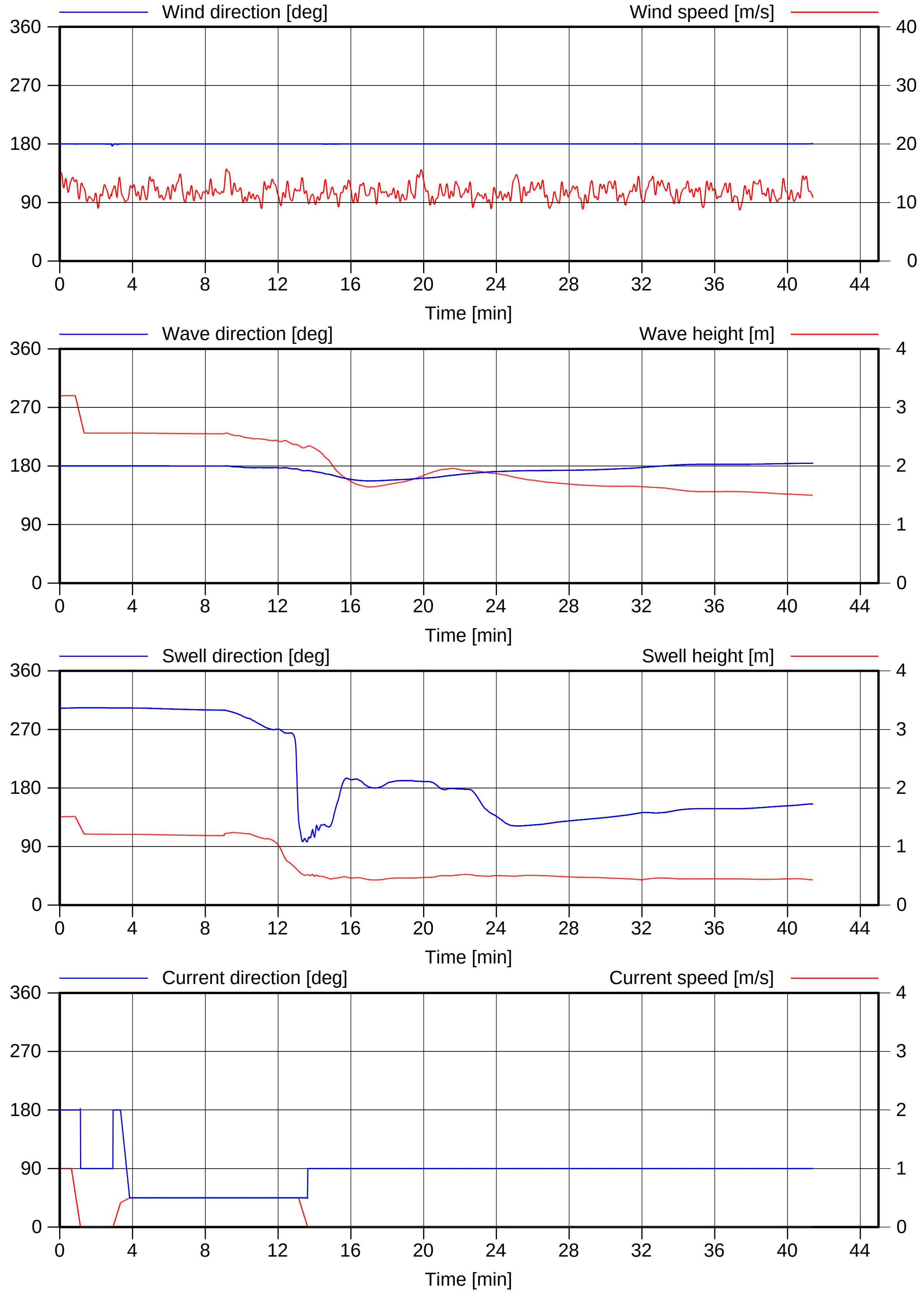
Run: 17	Malta
Arrival	Wind 12m/s from S
MARIN's Nautical Centre MSCN	Fig. 8.c



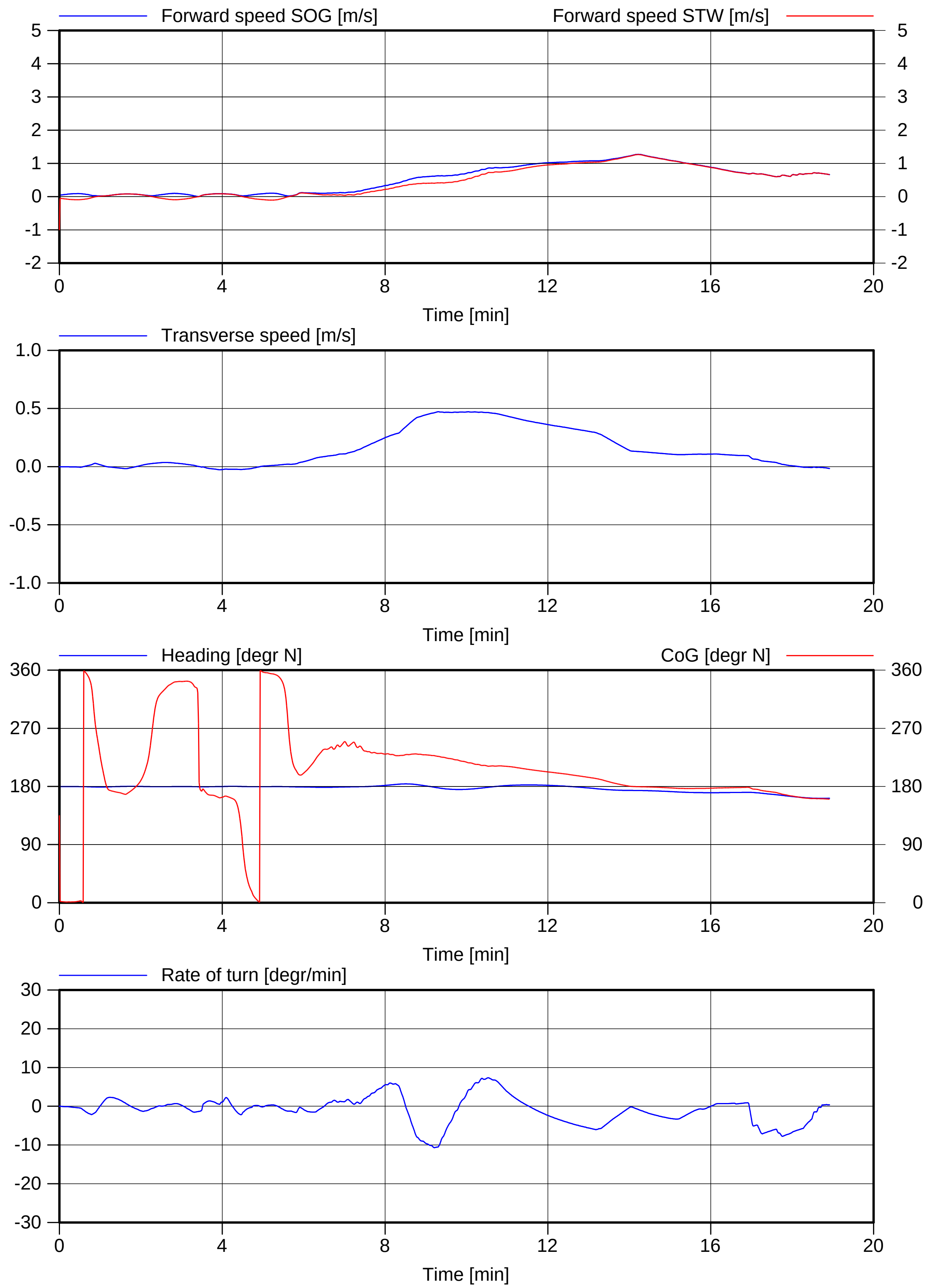
Run: 17	Malta
Arrival	Wind 12m/s from S
MARIN’s Nautical Centre MSCN	Fig. 8.d



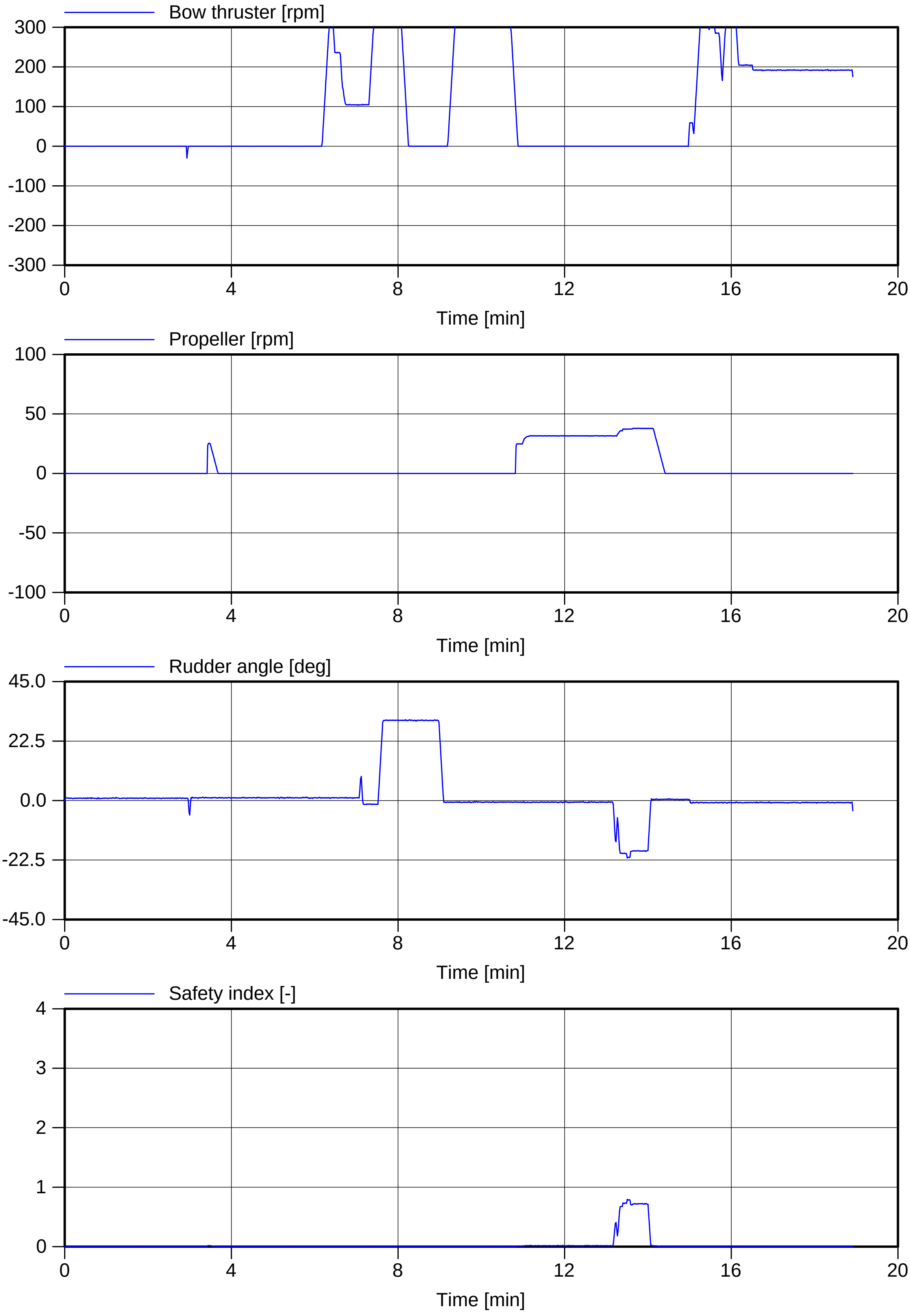
Run: 17	Malta
Arrival	Wind 12m/s from S
MARIN's Nautical Centre MSCN	Fig. 8.e



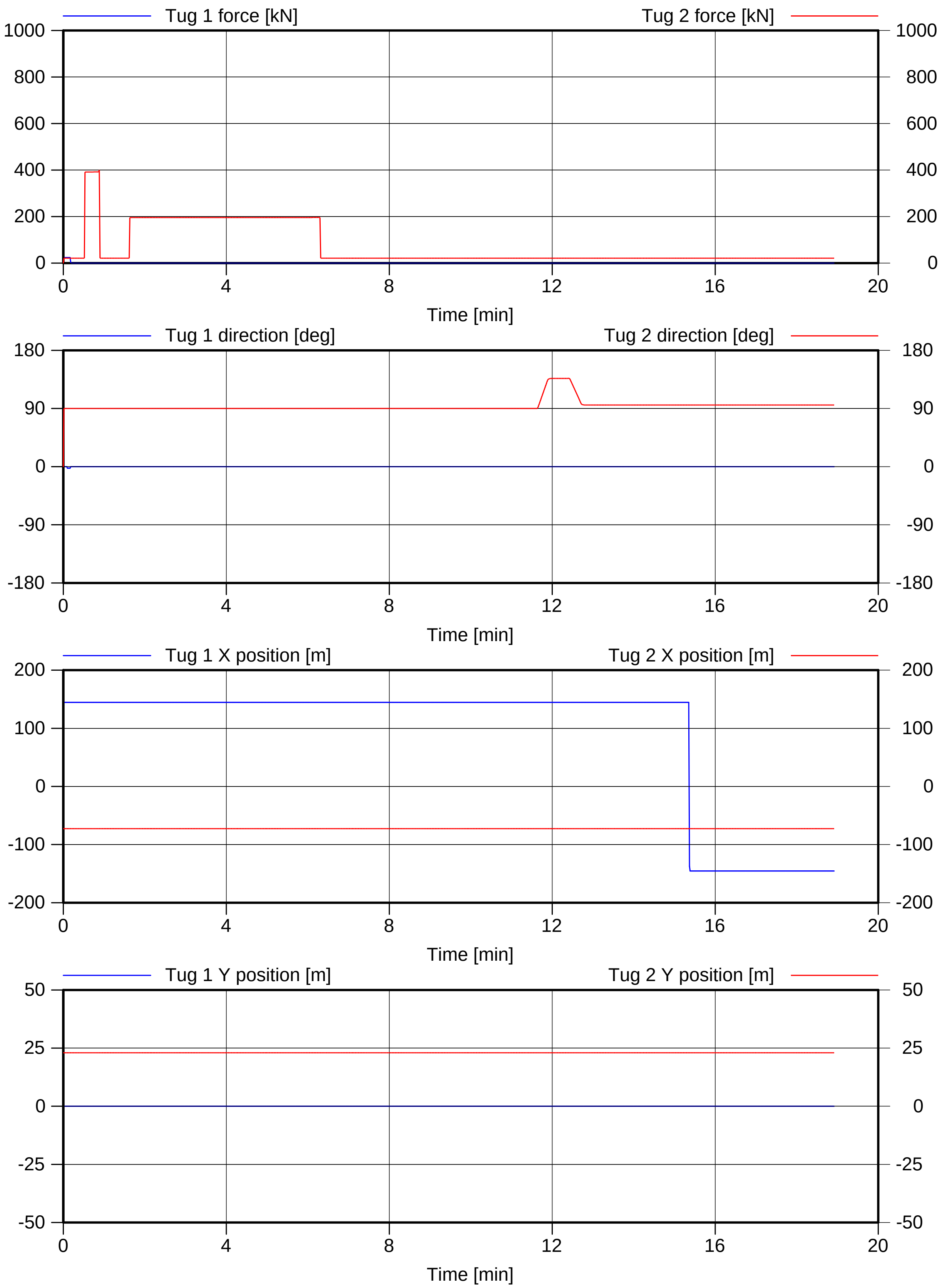
Run: 17	Malta
Arrival	Wind 12m/s from S
MARIN's Nautical Centre MSCN	Fig. 8.f



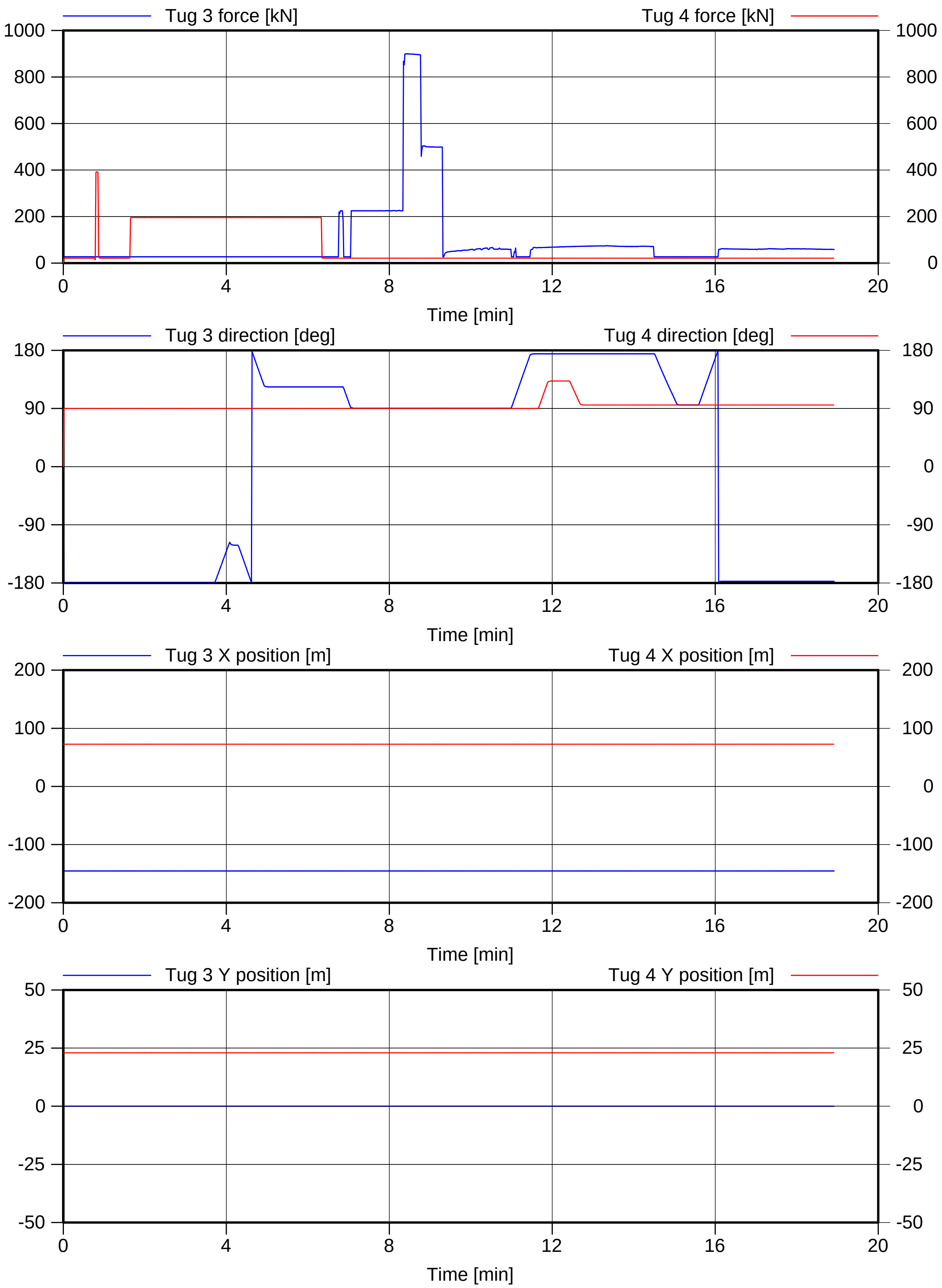
Run: 18	Malta
Departure	Wind 12m/s from S
MARIN's Nautical Centre MSCN	Fig. 9.a



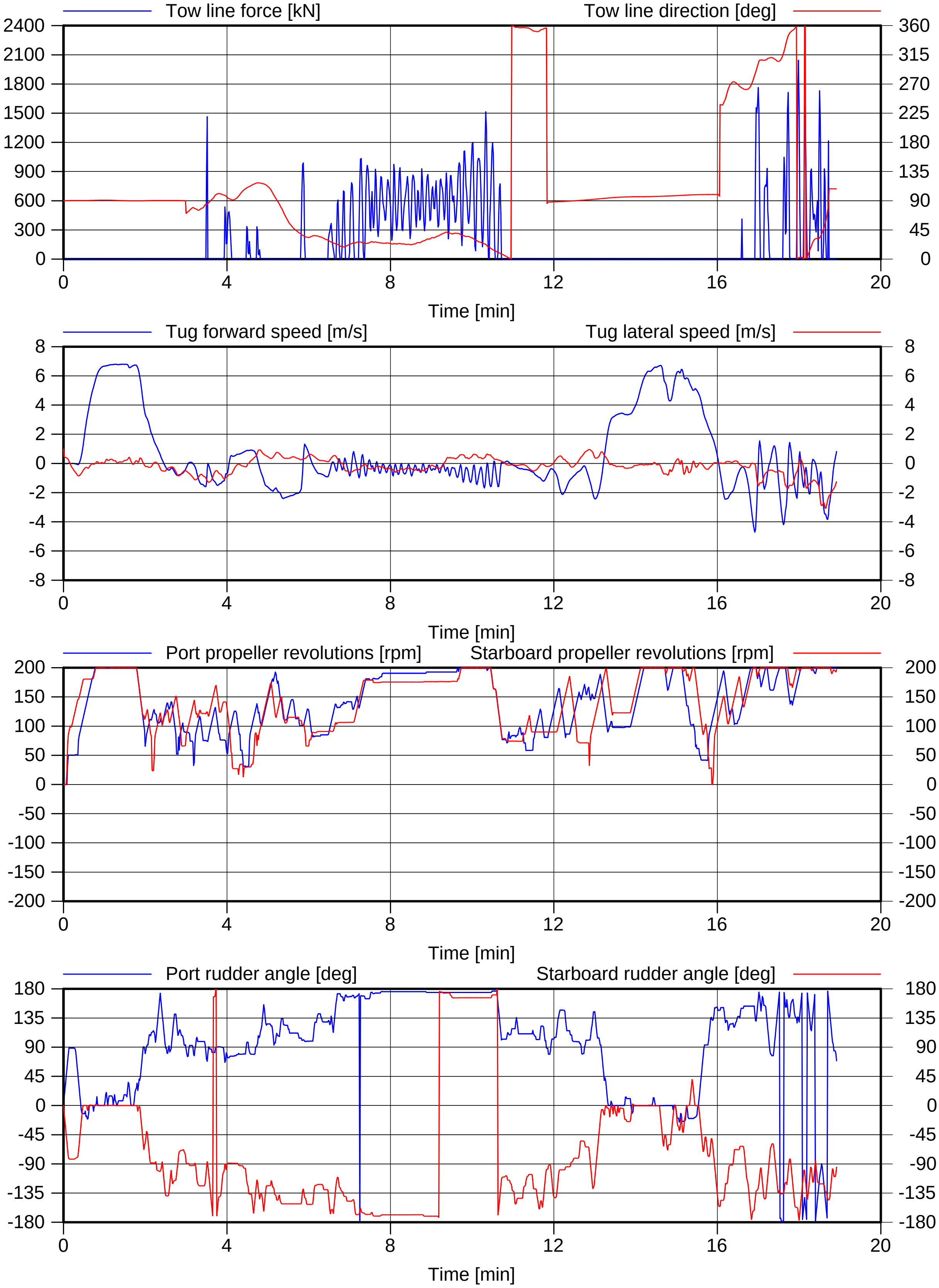
Run: 18	Malta
Departure	Wind 12m/s from S
MARIN's Nautical Centre MSCN	Fig. 9.b



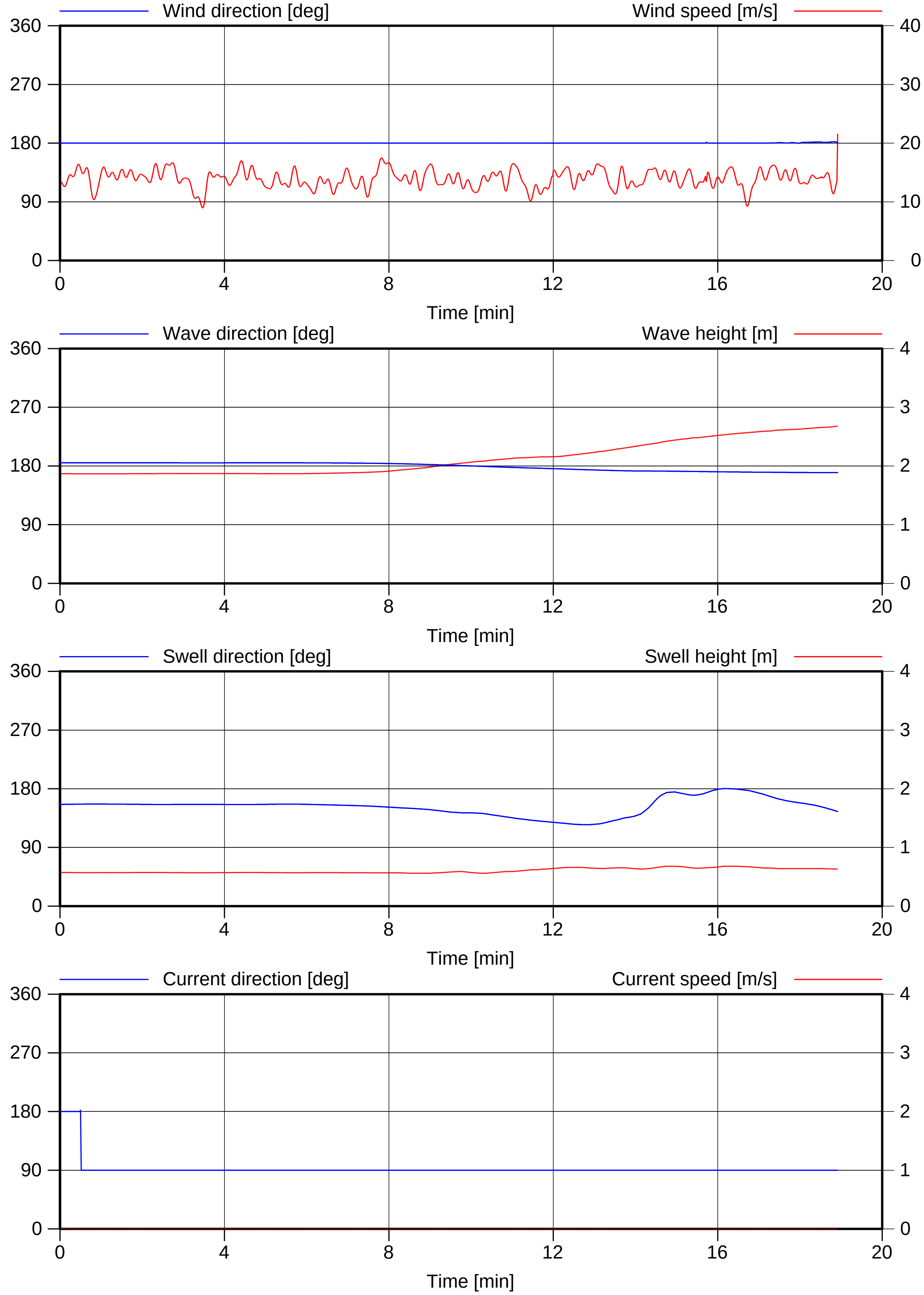
Run: 18	Malta
Departure	Wind 12m/s from S
MARIN's Nautical Centre MSCN	Fig. 9.c



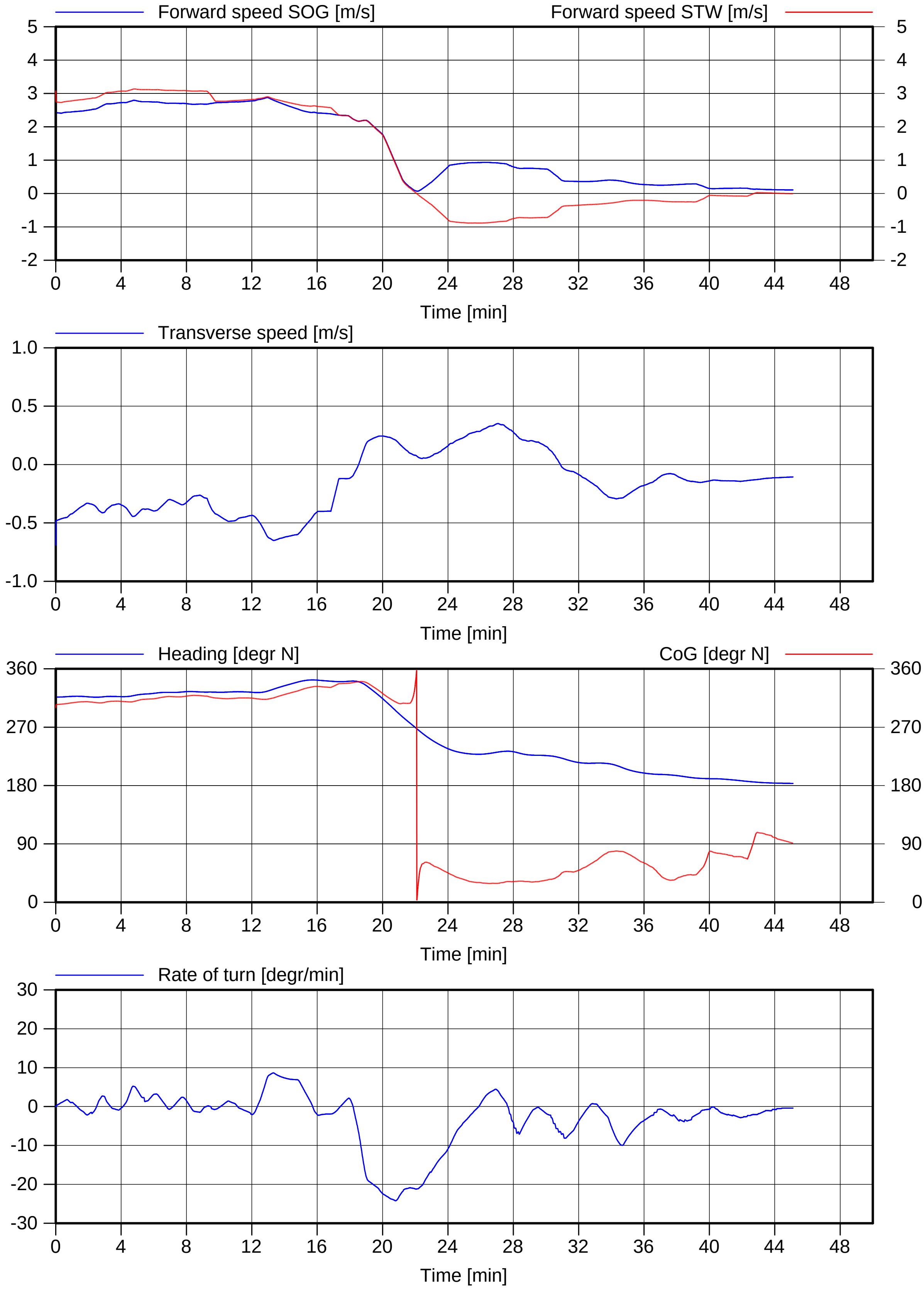
Run: 18	Malta
Departure	Wind 12m/s from S
MARIN's Nautical Centre MSCN	Fig. 9.d



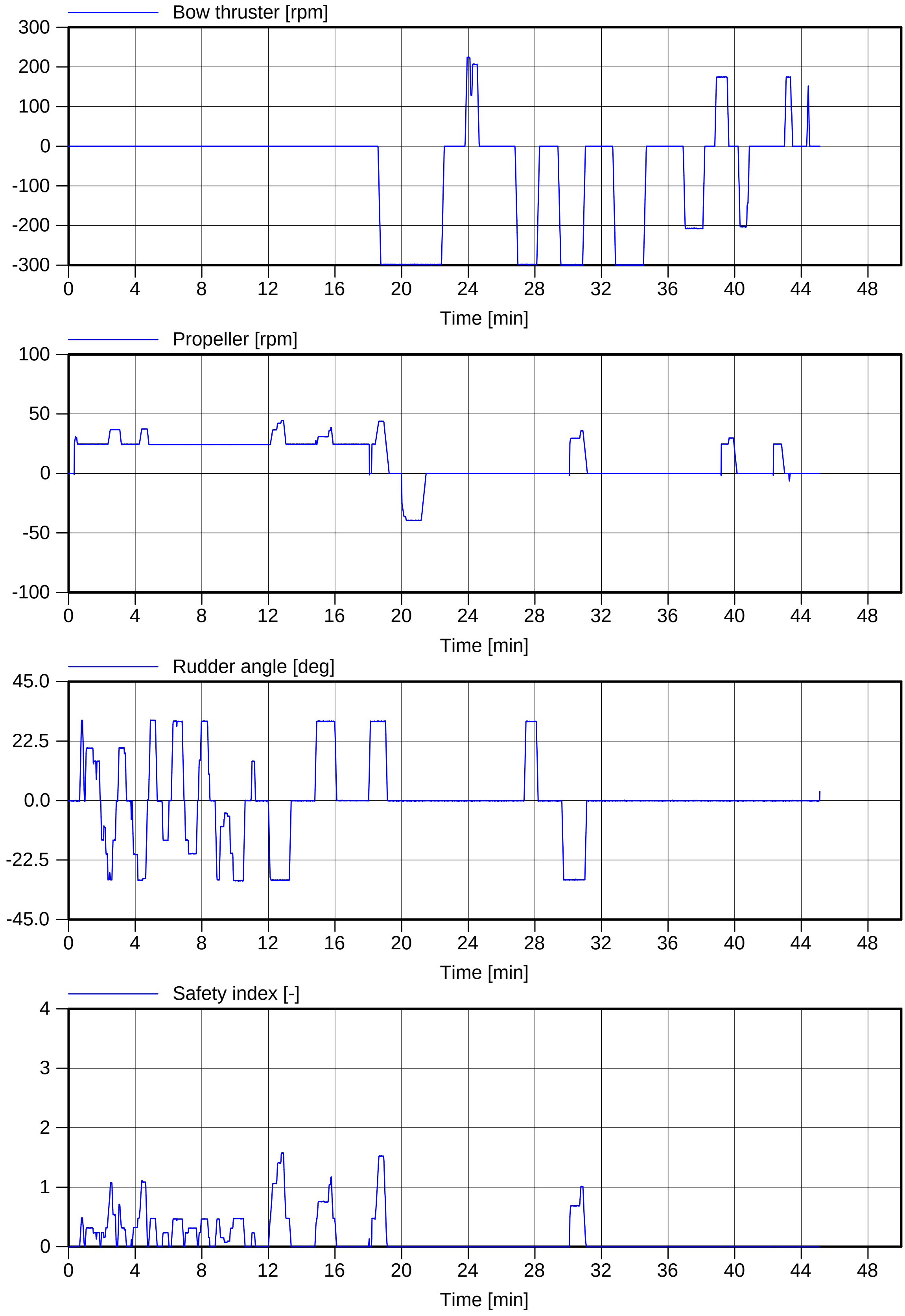
Run: 18	Malta
Departure	Wind 12m/s from S
MARIN's Nautical Centre MSCN	Fig. 9.e



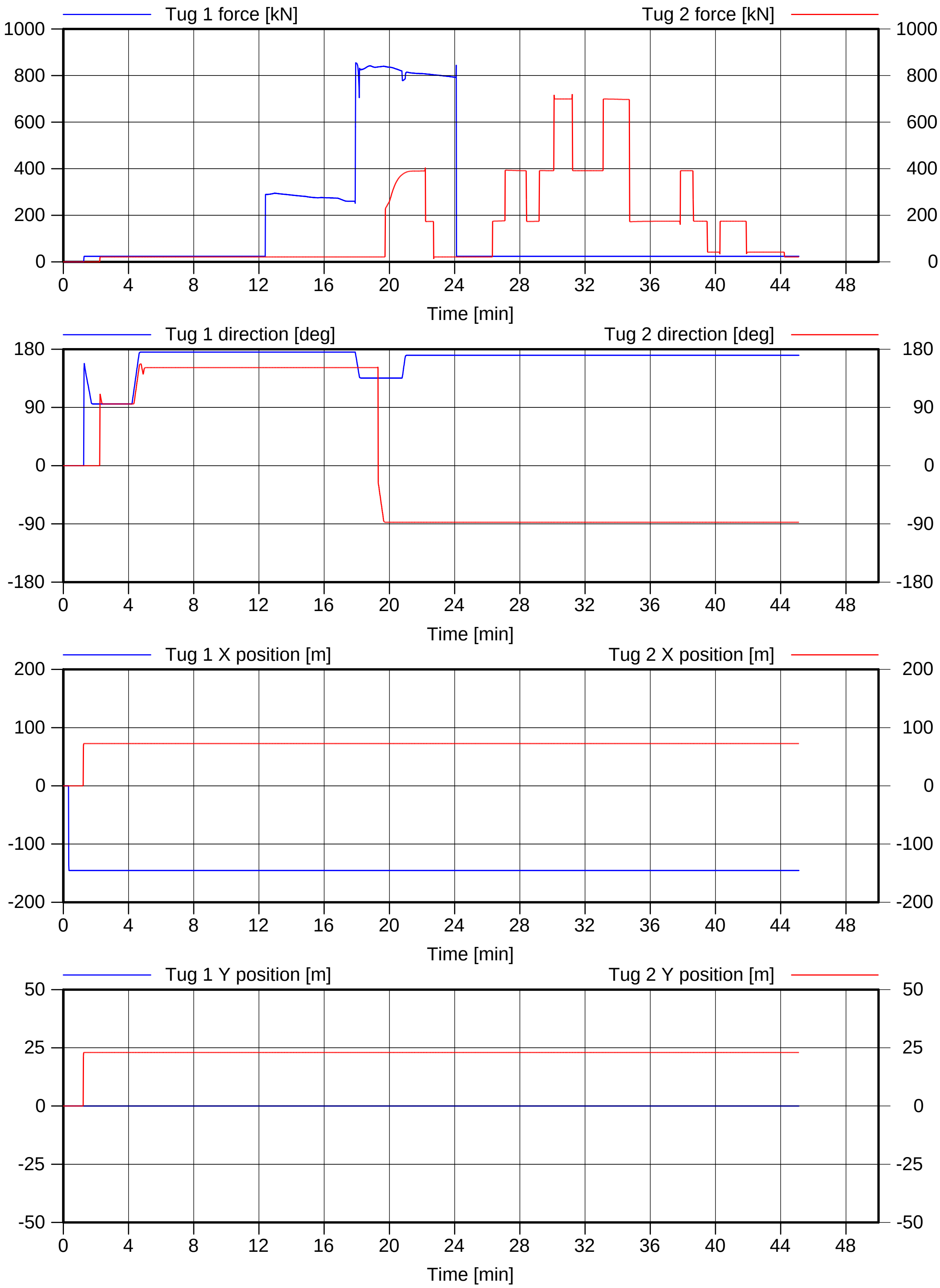
Run: 18	Malta
Departure	Wind 12m/s from S
MARIN's Nautical Centre MSCN	Fig. 9.f



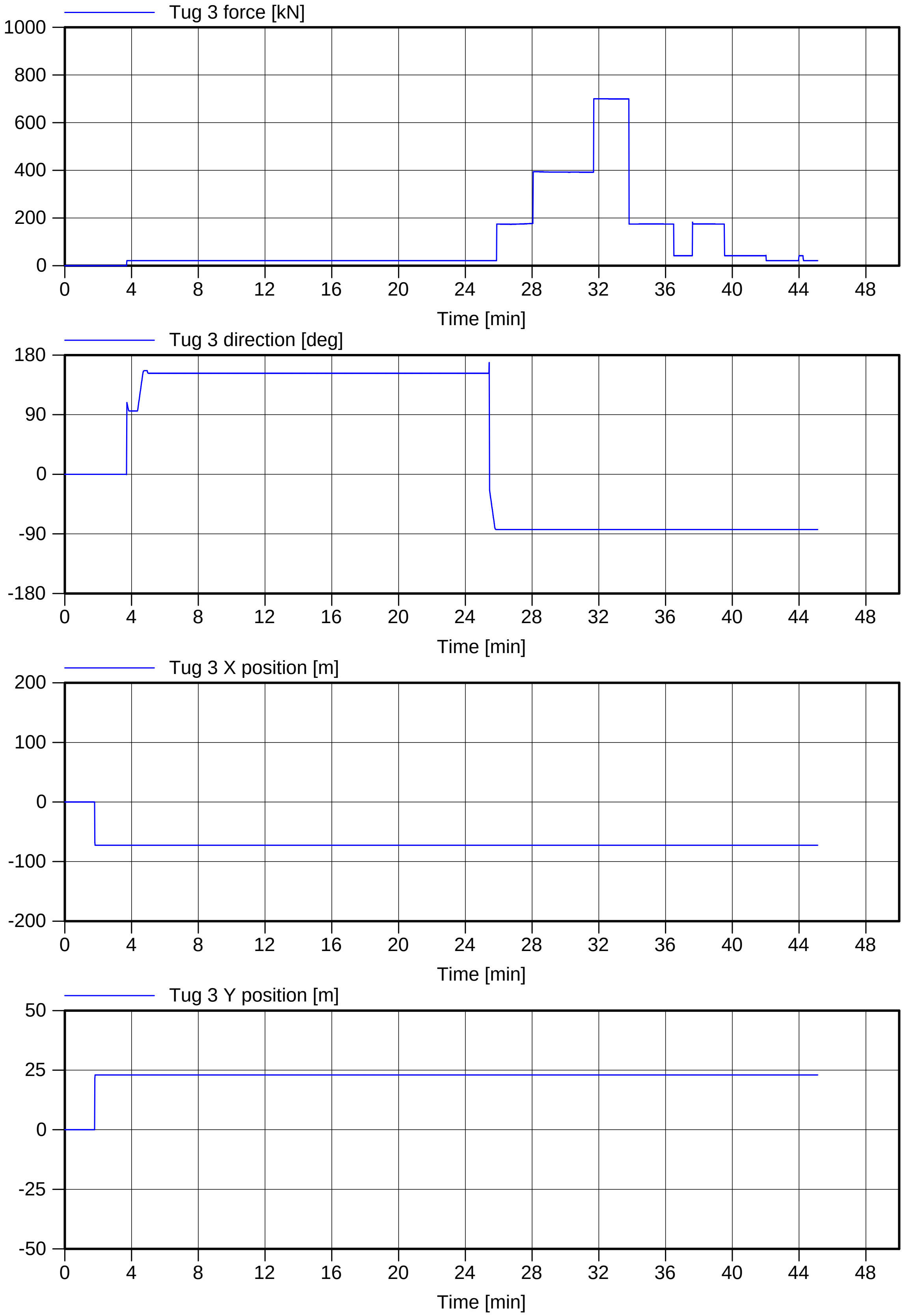
Run: 19	Malta
Arrival	Wind 12m/s from SE
MARIN's Nautical Centre MSCN	Fig. 10.a



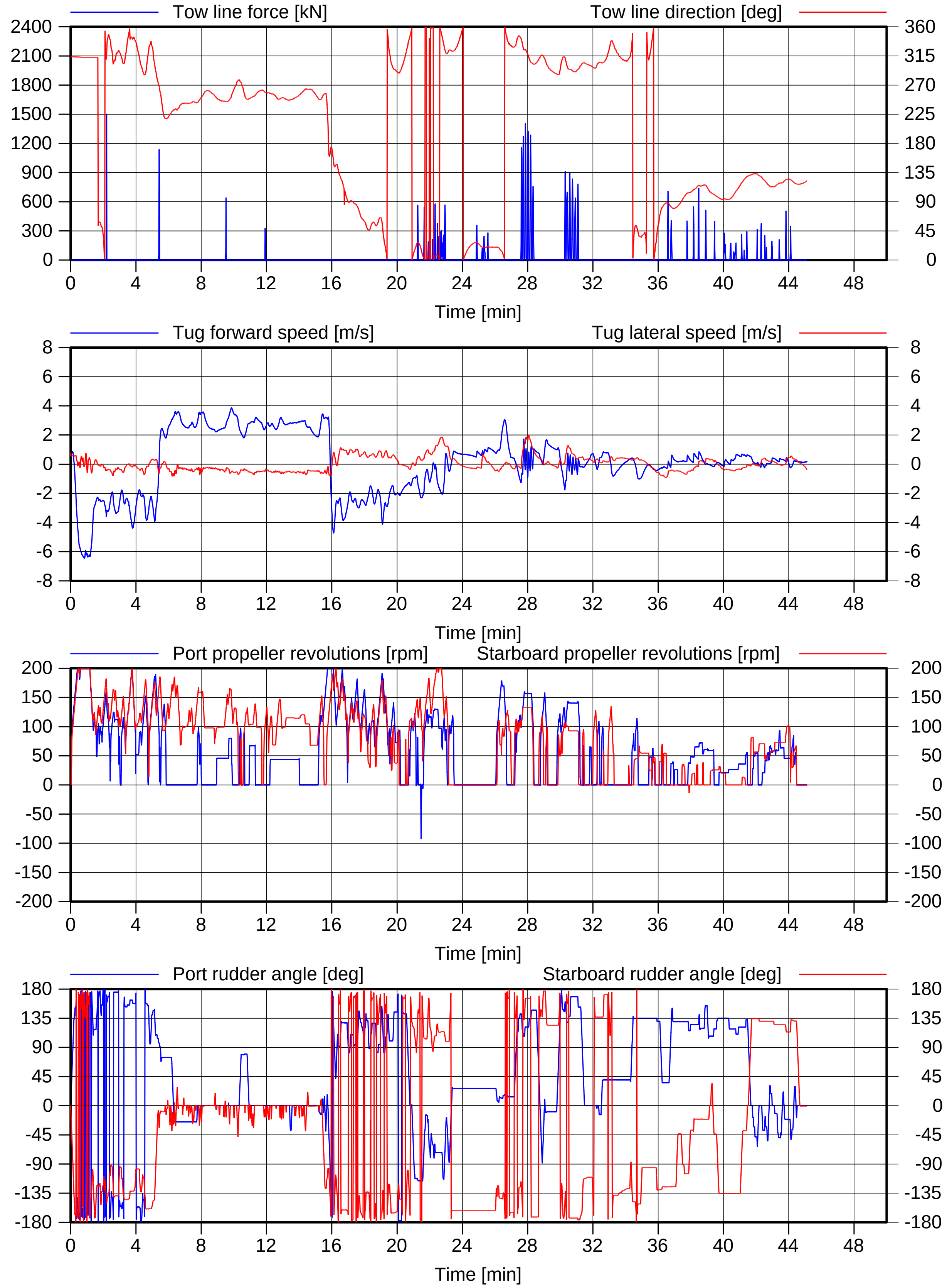
Run: 19	Malta
Arrival	Wind 12m/s from SE
MARIN's Nautical Centre MSCN	Fig. 10.b



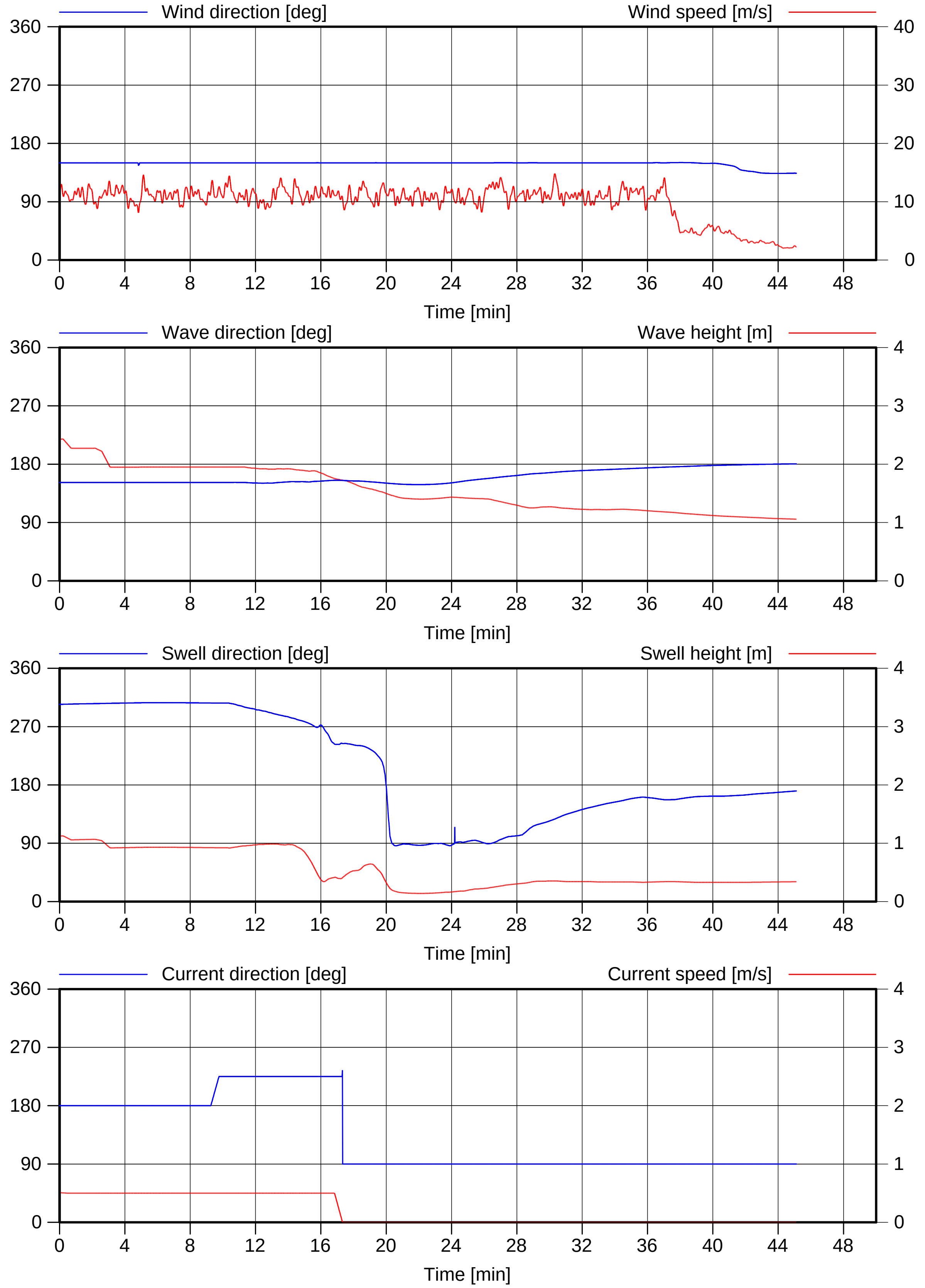
Run: 19	Malta
Arrival	Wind 12m/s from SE
MARIN's Nautical Centre MSCN	Fig. 10.c



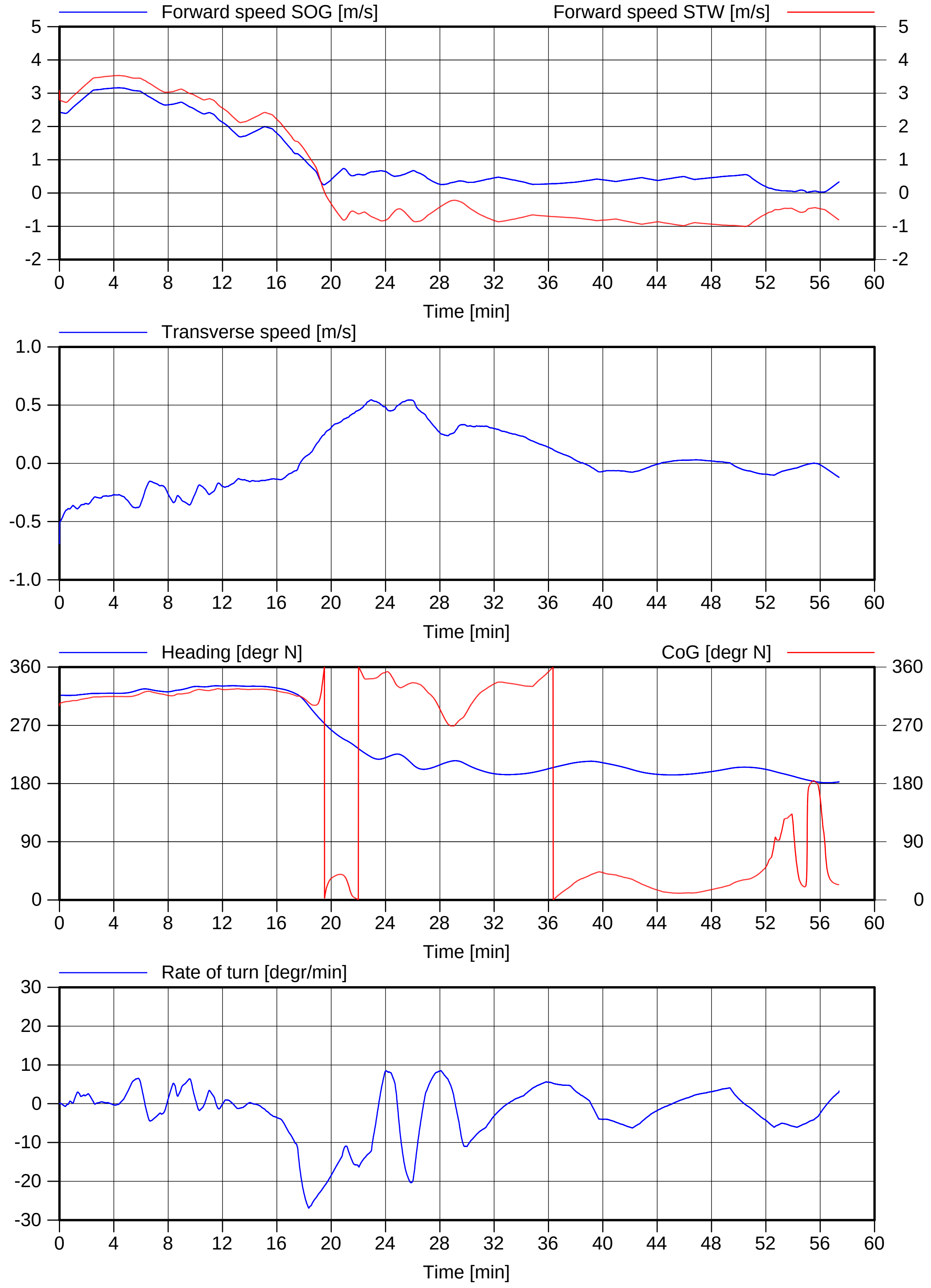
Run: 19	Malta
Arrival	Wind 12m/s from SE
MARIN's Nautical Centre MSCN	Fig. 10.d



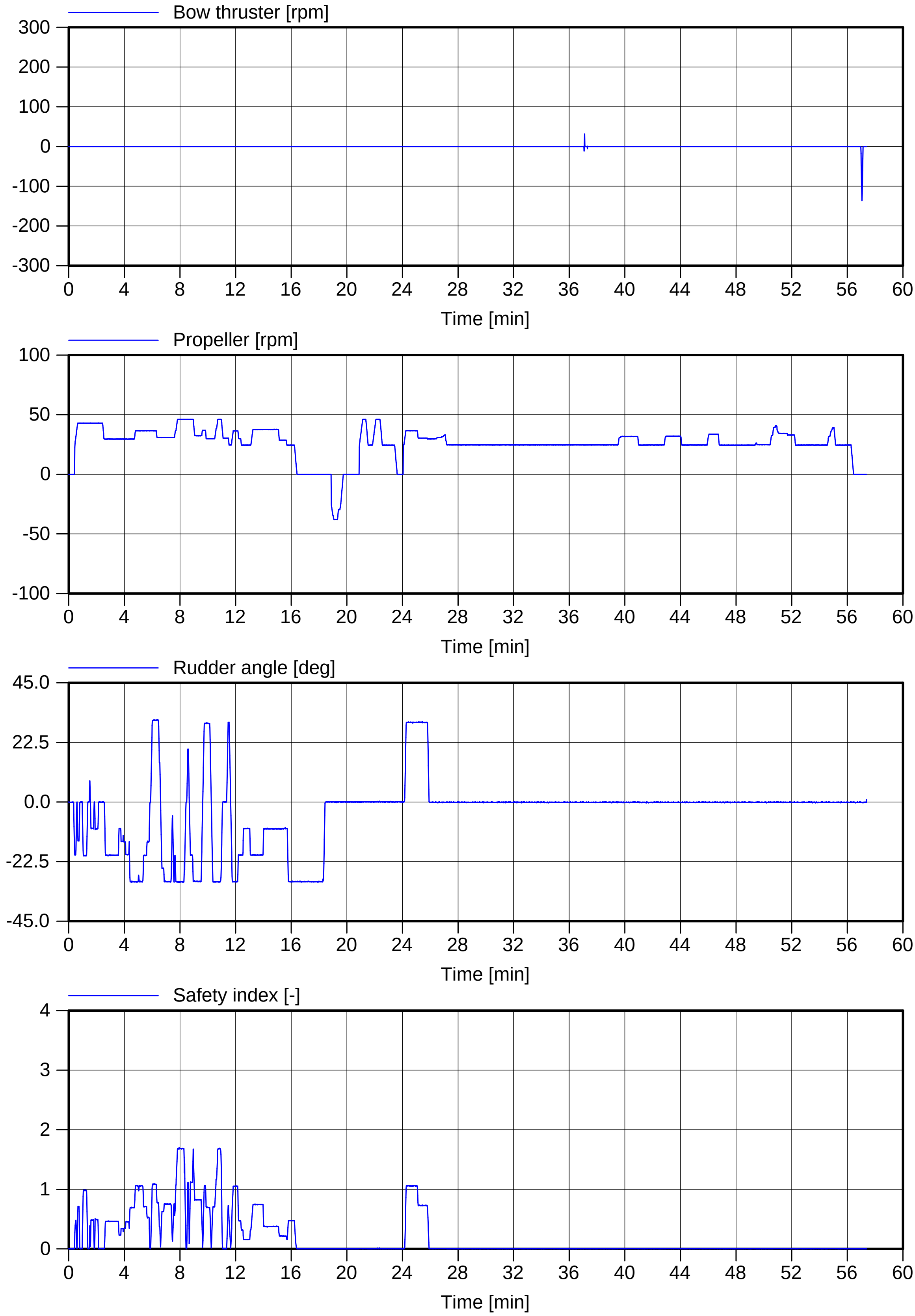
Run: 19	Malta
Arrival	Wind 12m/s from SE
MARIN's Nautical Centre MSCN	Fig. 10.e



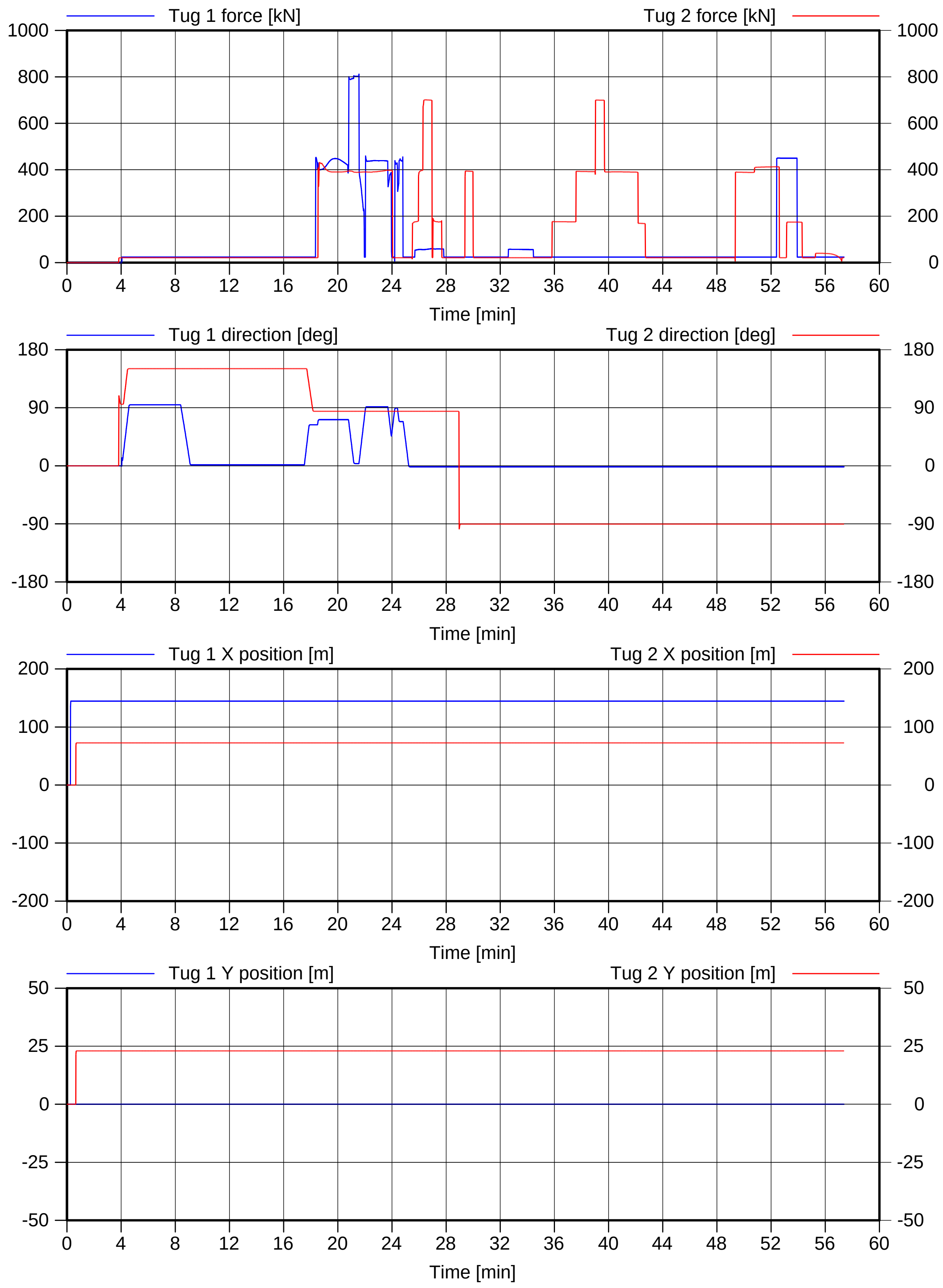
Run: 19	Malta
Arrival	Wind 12m/s from SE
MARIN's Nautical Centre MSCN	Fig. 10.f



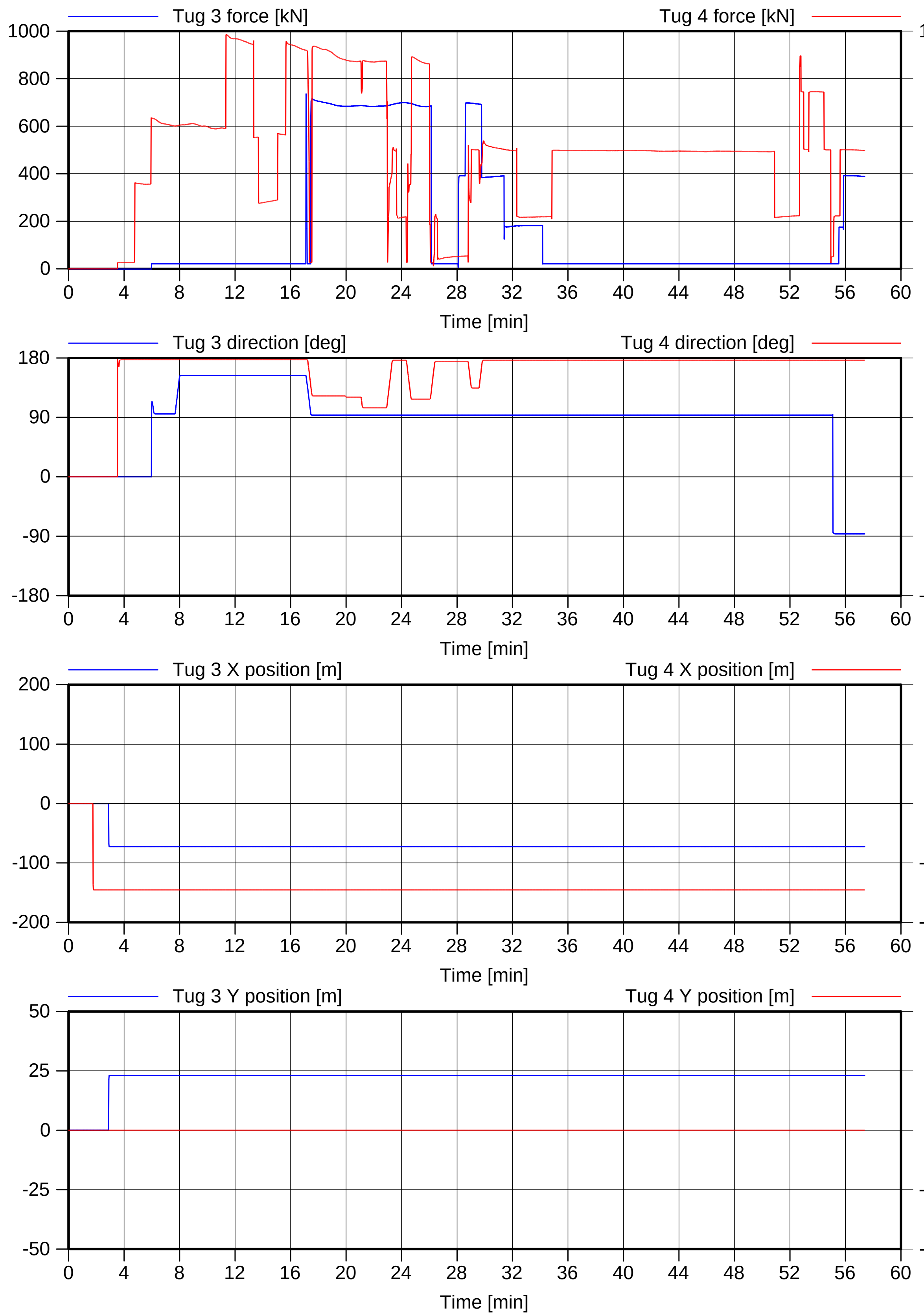
Run: 20	Malta
Arrival	Wind 12m/s from S
MARIN's Nautical Centre MSCN	Fig. 11.a



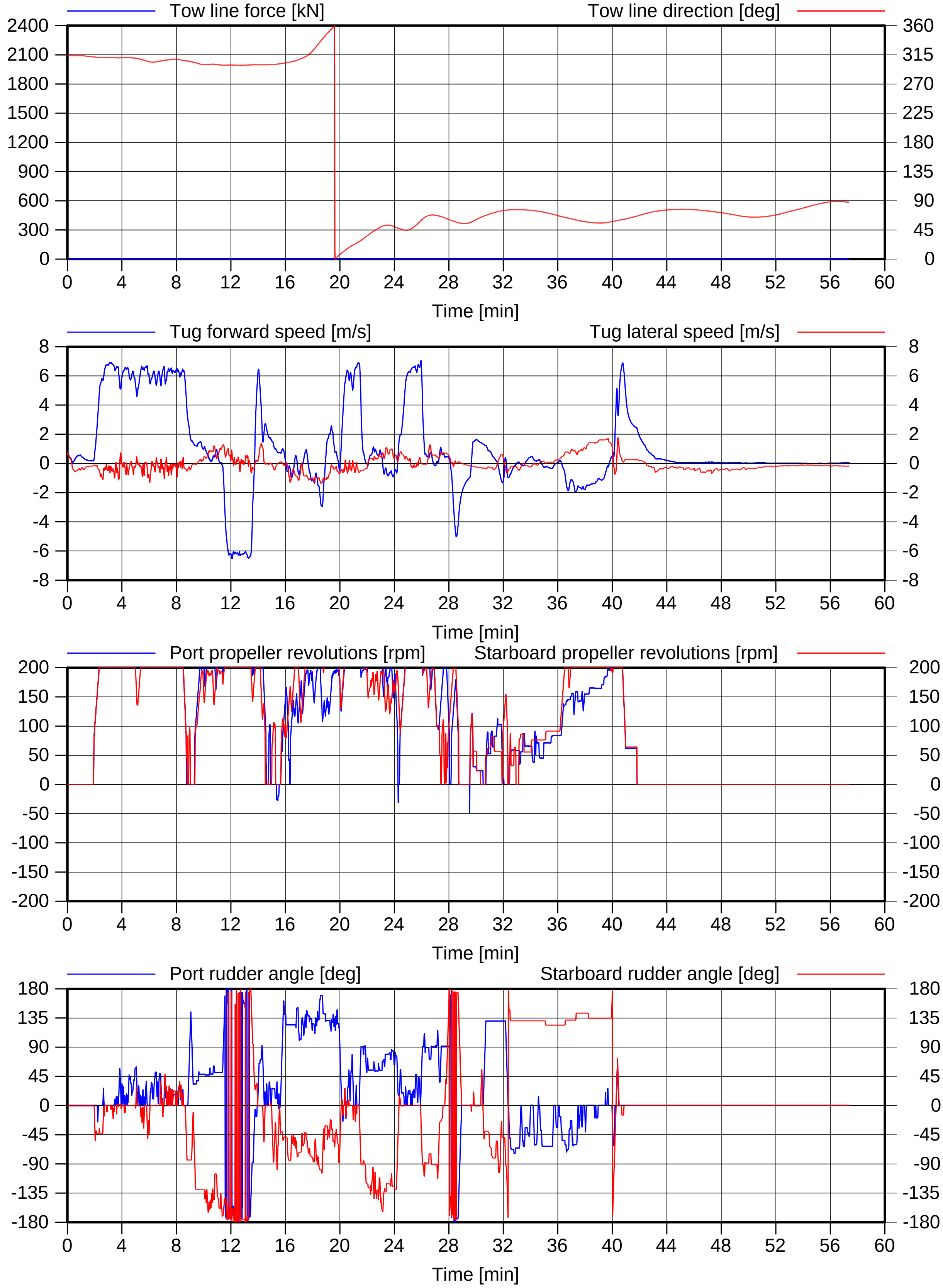
Run: 20	Malta
Arrival	Wind 12m/s from S
MARIN's Nautical Centre MSCN	Fig. 11.b



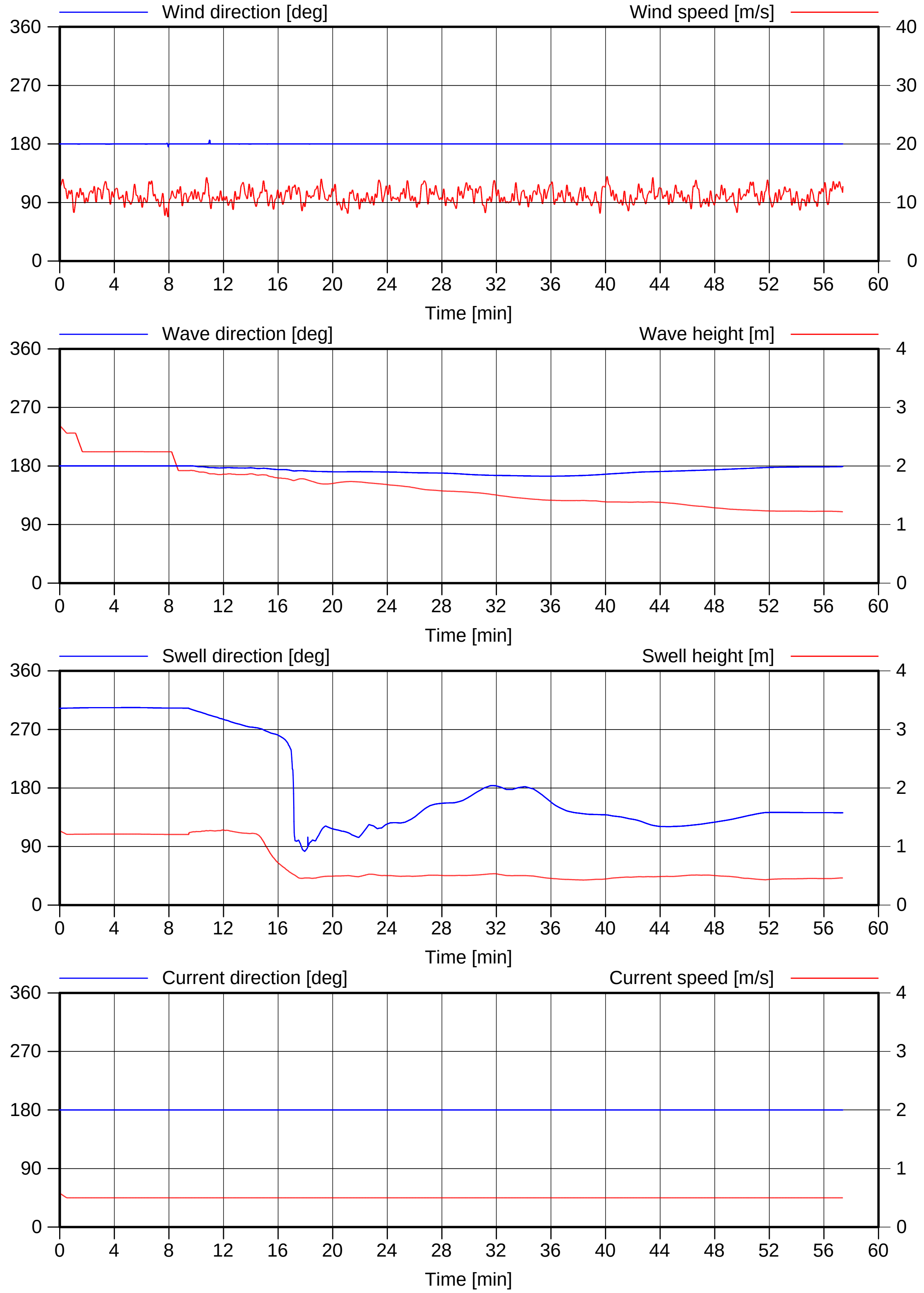
Run: 20	Malta
Arrival	Wind 12m/s from S
MARIN's Nautical Centre MSCN	Fig. 11.c



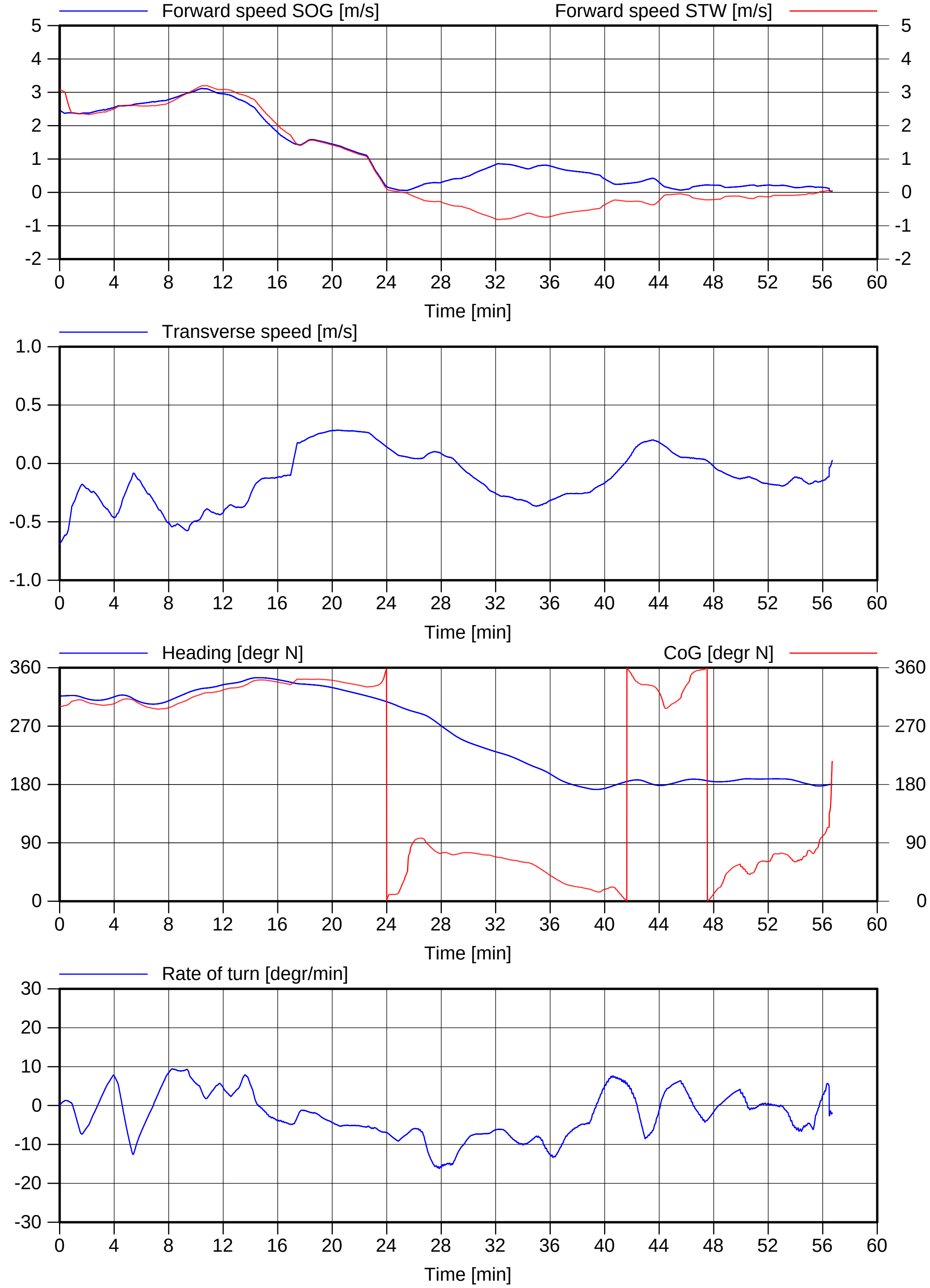
Run: 20	Malta
Arrival	Wind 12m/s from S
MARIN's Nautical Centre MSCN	Fig. 11.d



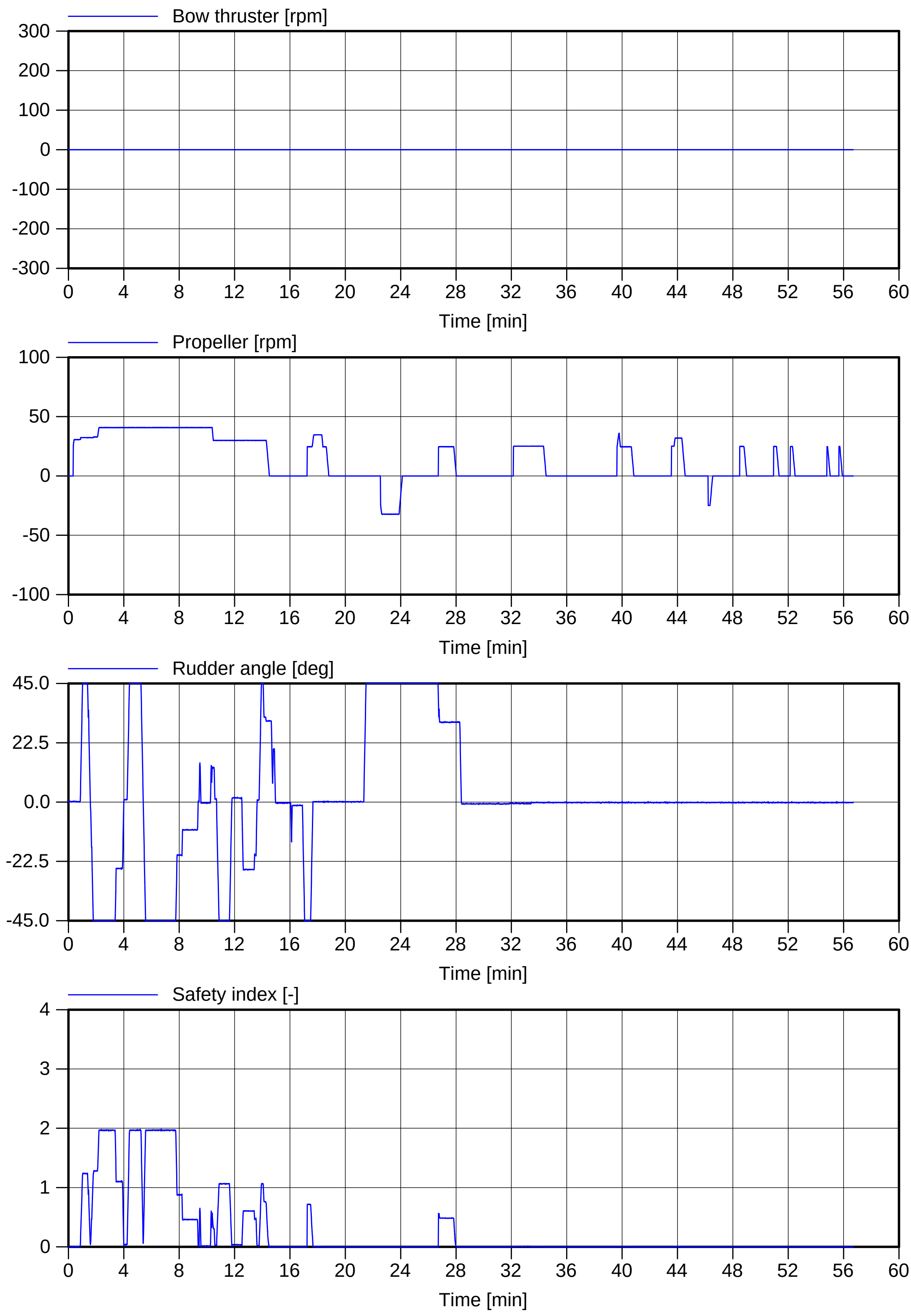
Run: 20	Malta
Arrival	Wind 12m/s from S
MARIN's Nautical Centre MSCN	Fig. 11.e



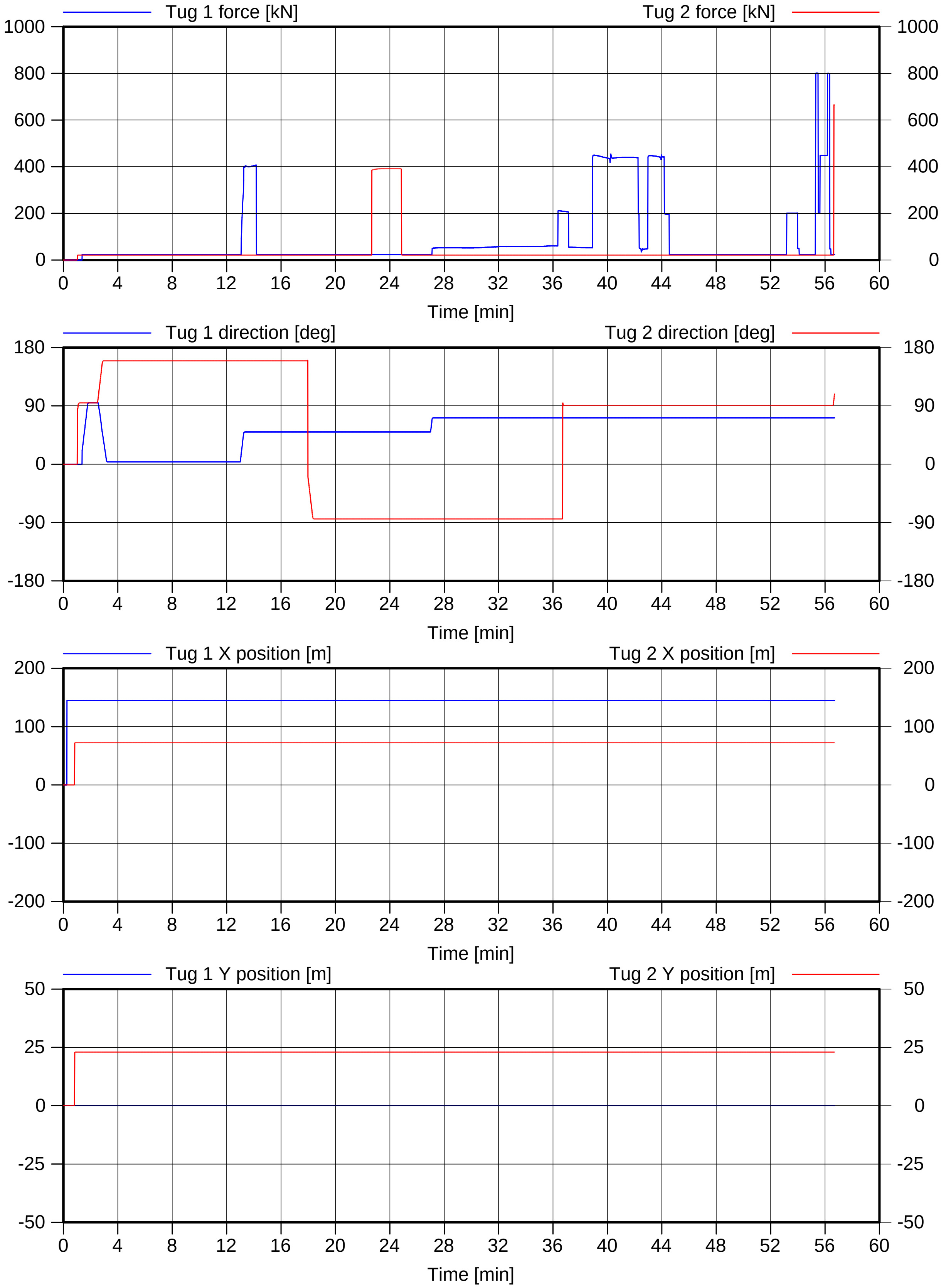
Run: 20	Malta
Arrival	Wind 12m/s from S
MARIN's Nautical Centre MSCN	Fig. 11.f



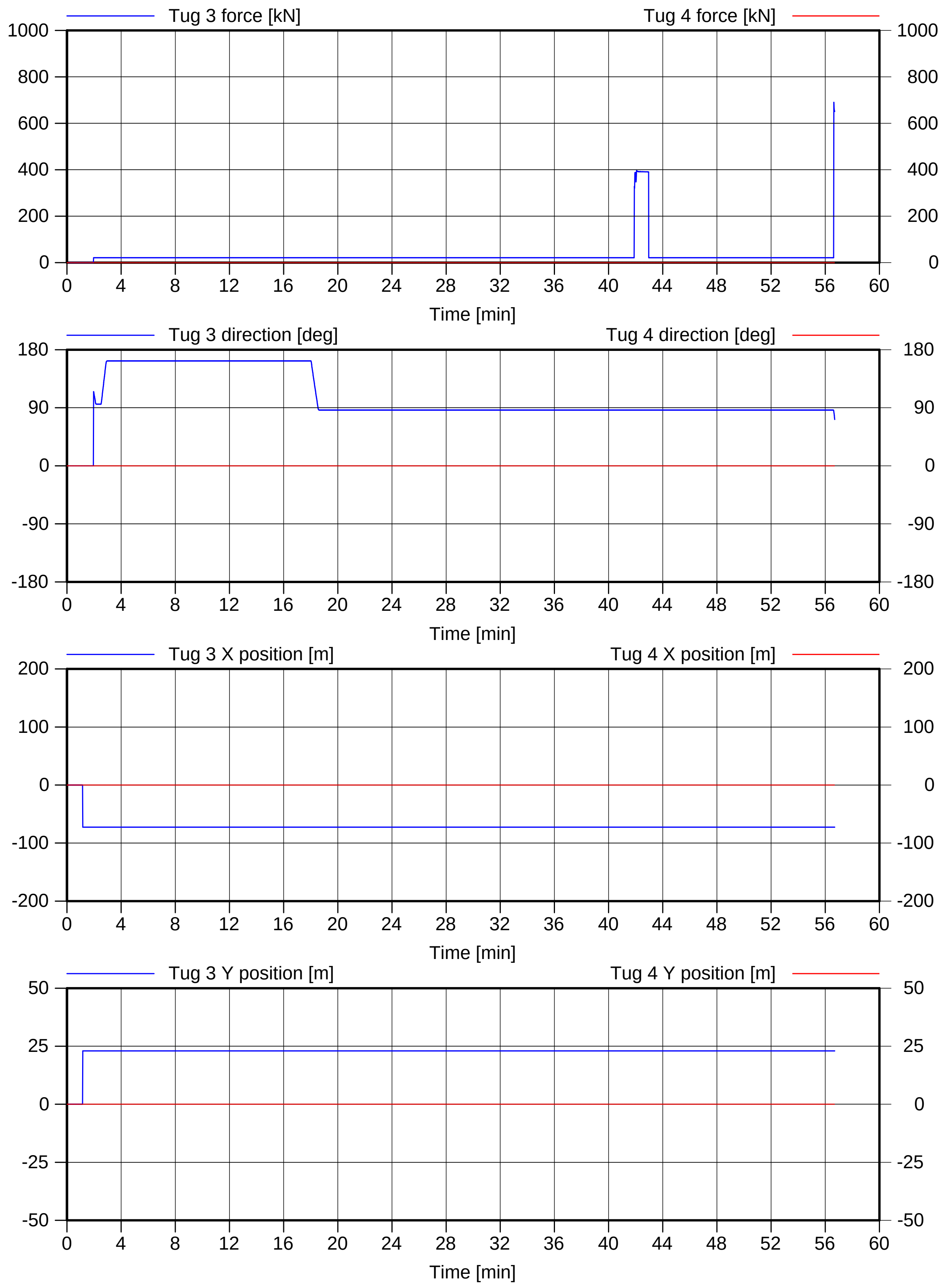
Run: 21	Malta
Arrival	Wind 12m/s from NW
MARIN's Nautical Centre MSCN	Fig. 12.a



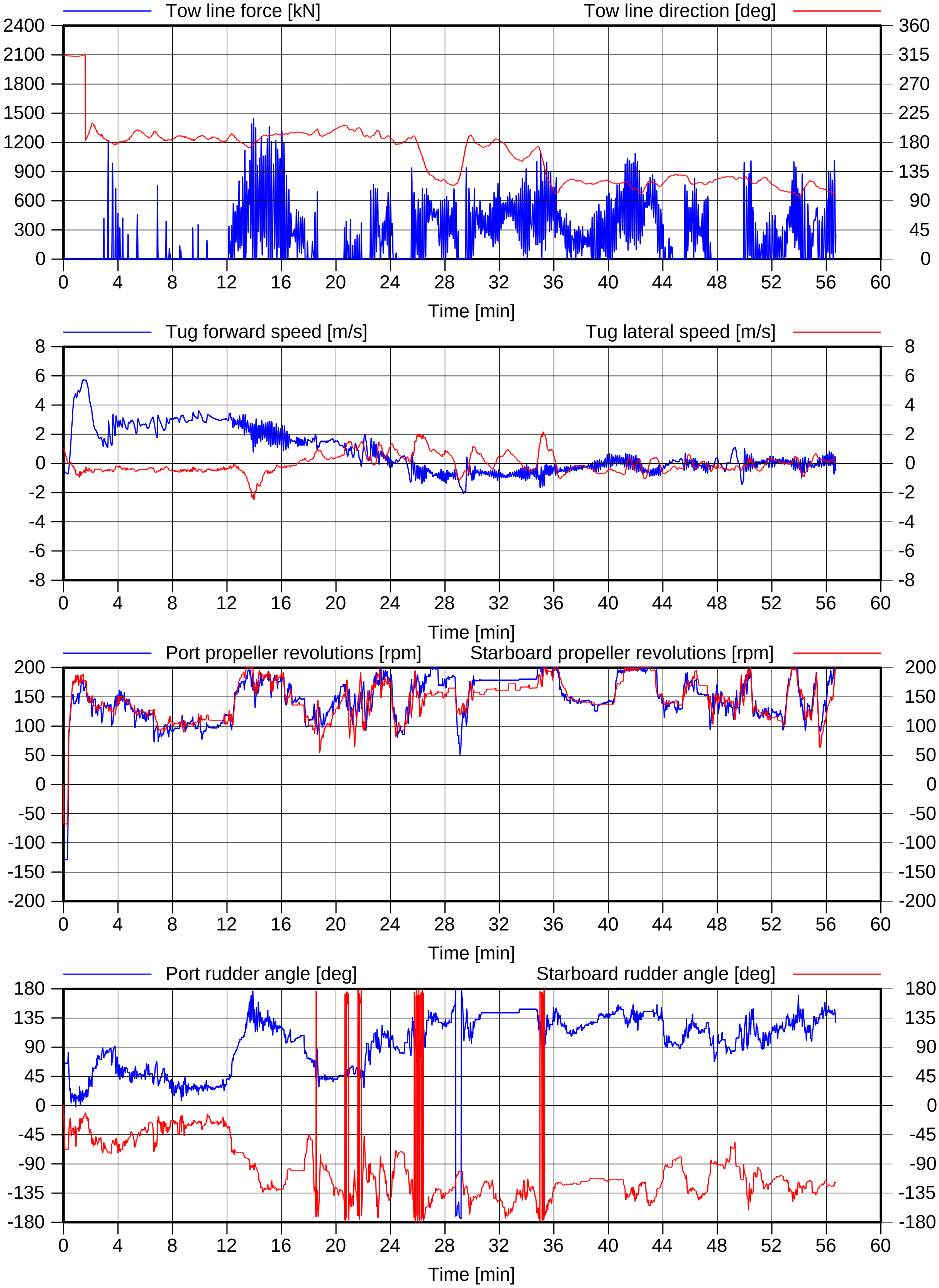
Run: 21	Malta
Arrival	Wind 12m/s from NW
MARIN's Nautical Centre MSCN	Fig. 12.b



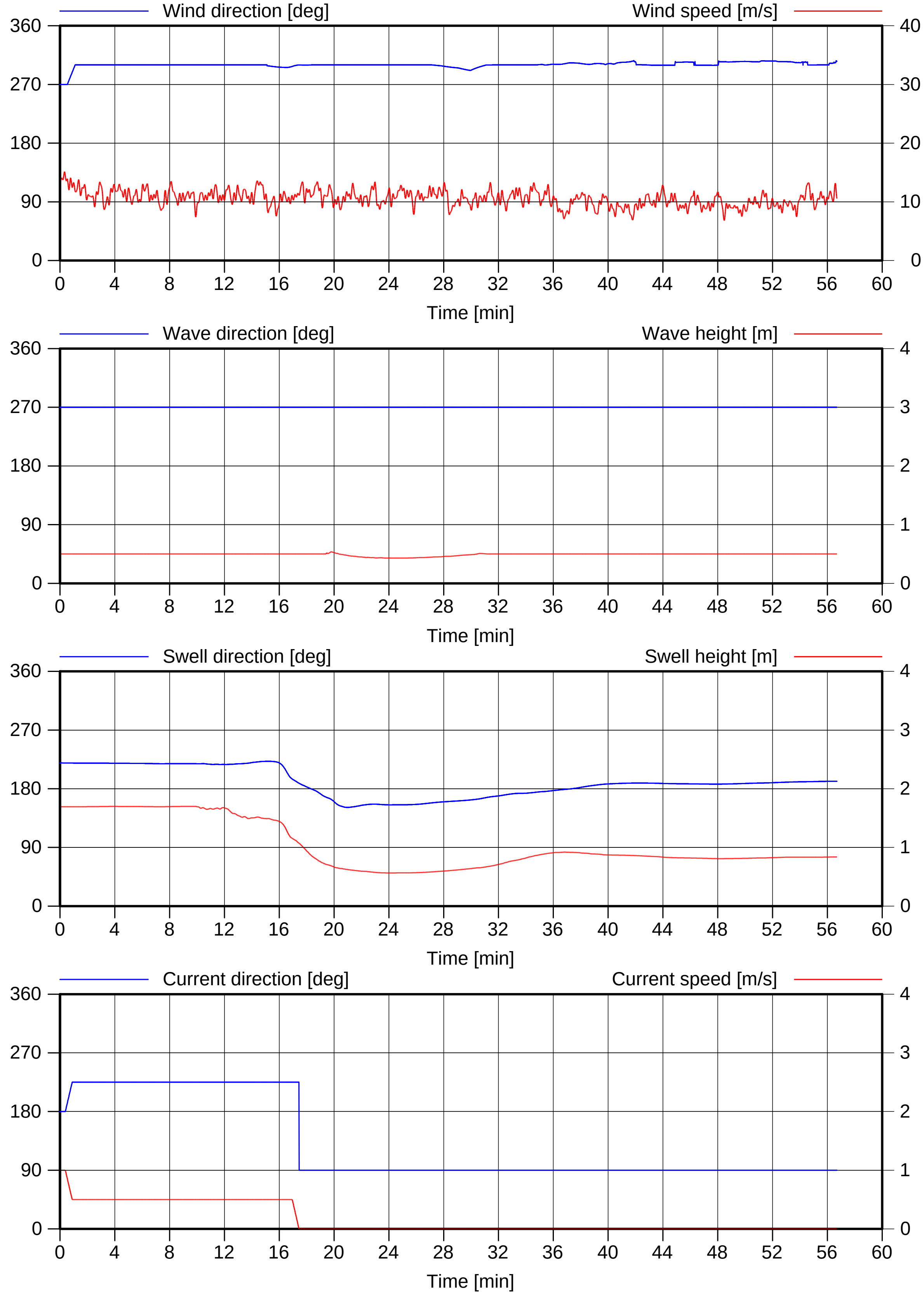
Run: 21	Malta
Arrival	Wind 12m/s from NW
MARIN's Nautical Centre MSCN	Fig. 12.c



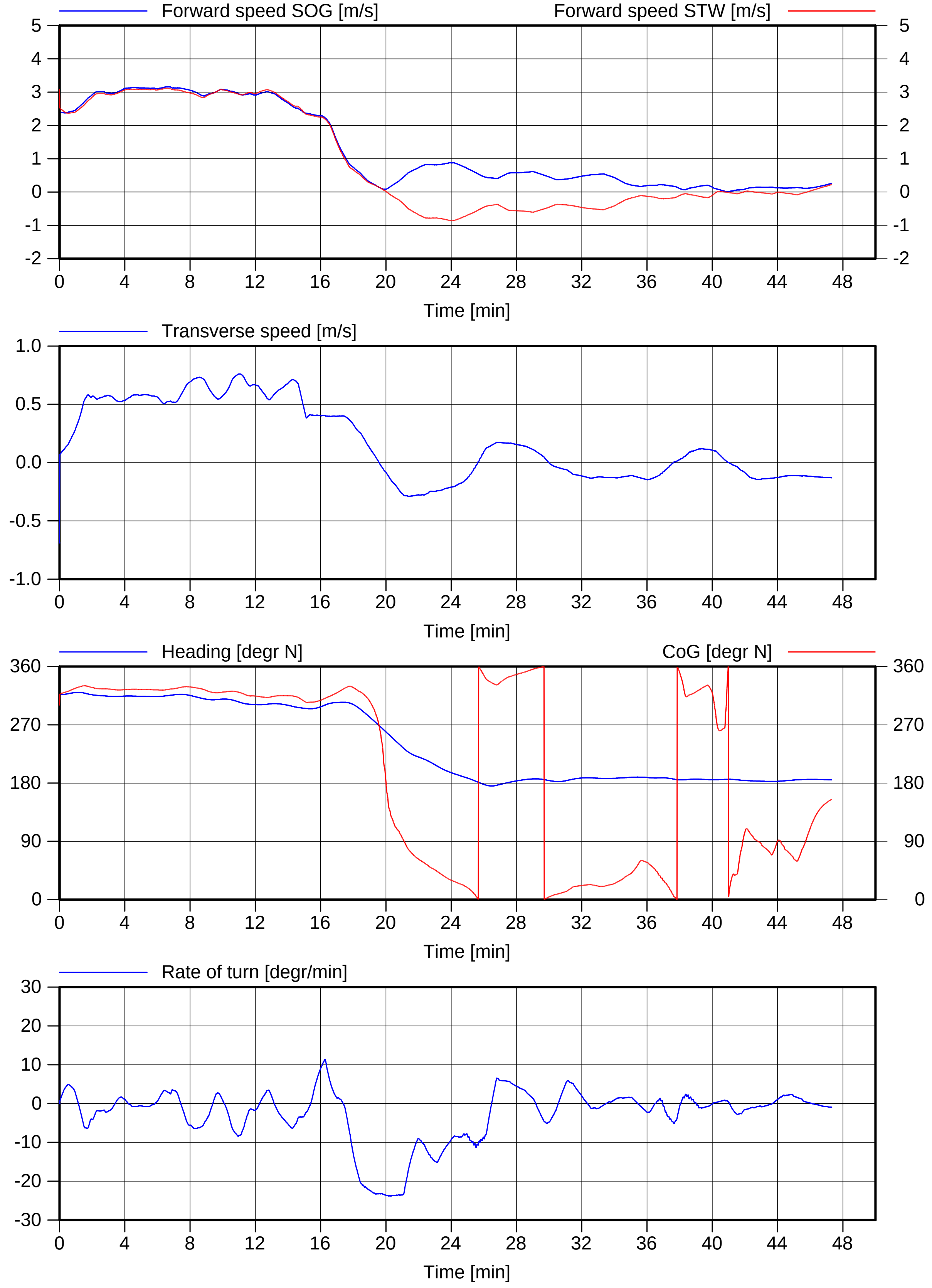
Run: 21	Malta
Arrival	Wind 12m/s from NW
MARIN's Nautical Centre MSCN	Fig. 12.d



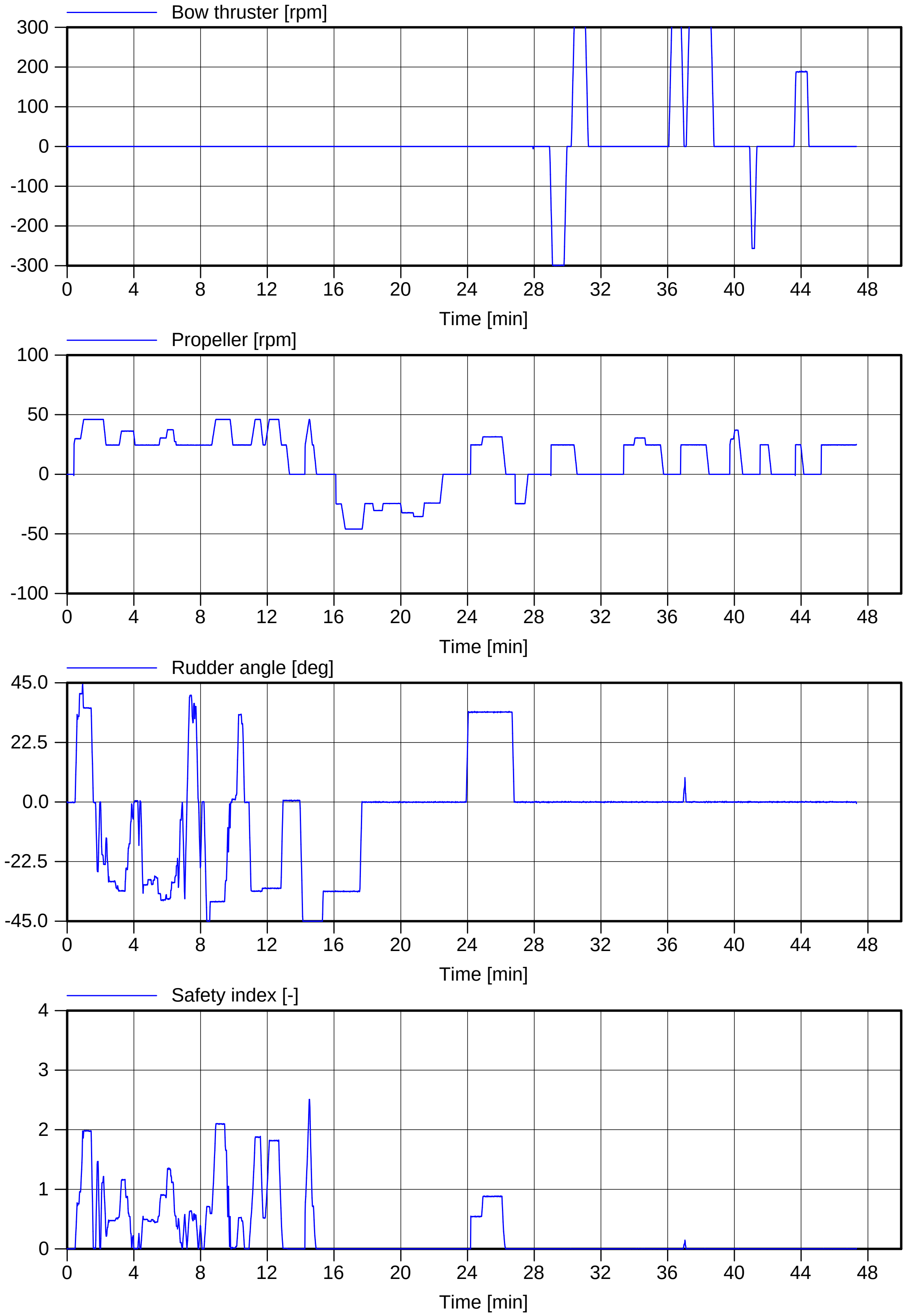
Run: 21	Malta
Arrival	Wind 12m/s from NW
MARIN's Nautical Centre MSCN	Fig. 12.e



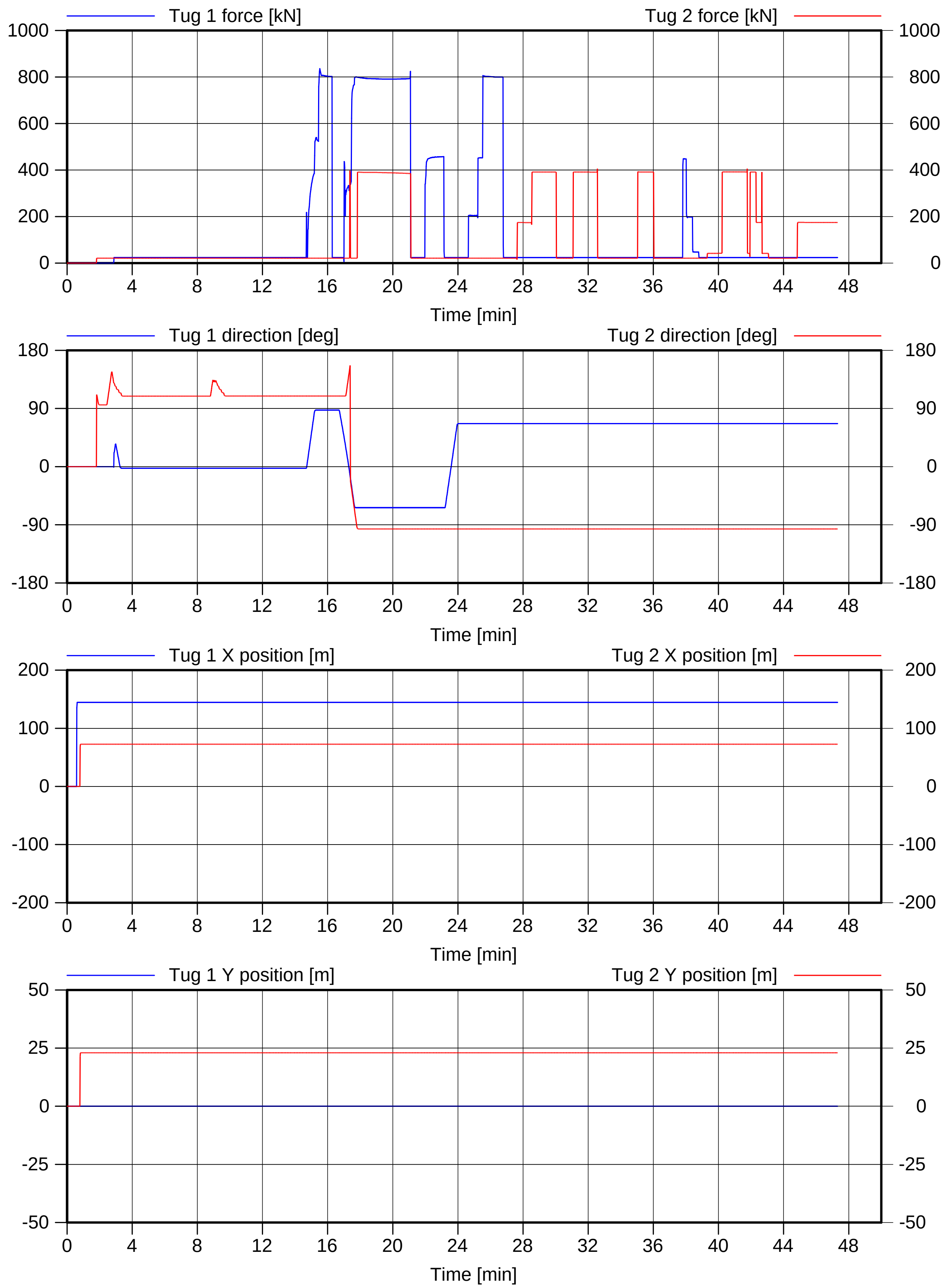
Run: 21	Malta
Arrival	Wind 12m/s from NW
MARIN's Nautical Centre MSCN	Fig. 12.f



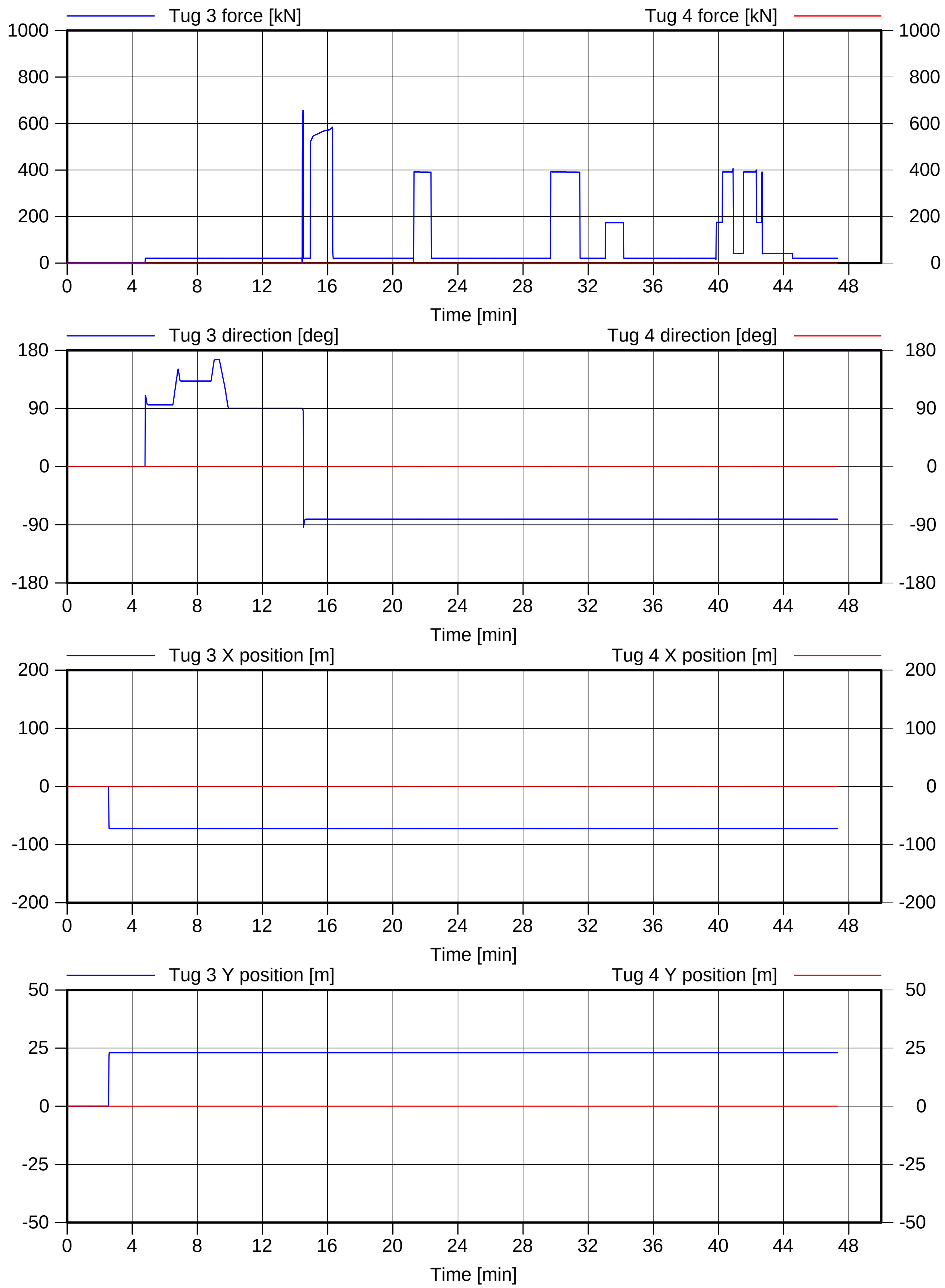
Run: 22	Malta
Arrival	Wind 12m/s from S
MARIN's Nautical Centre MSCN	Fig. 13.a



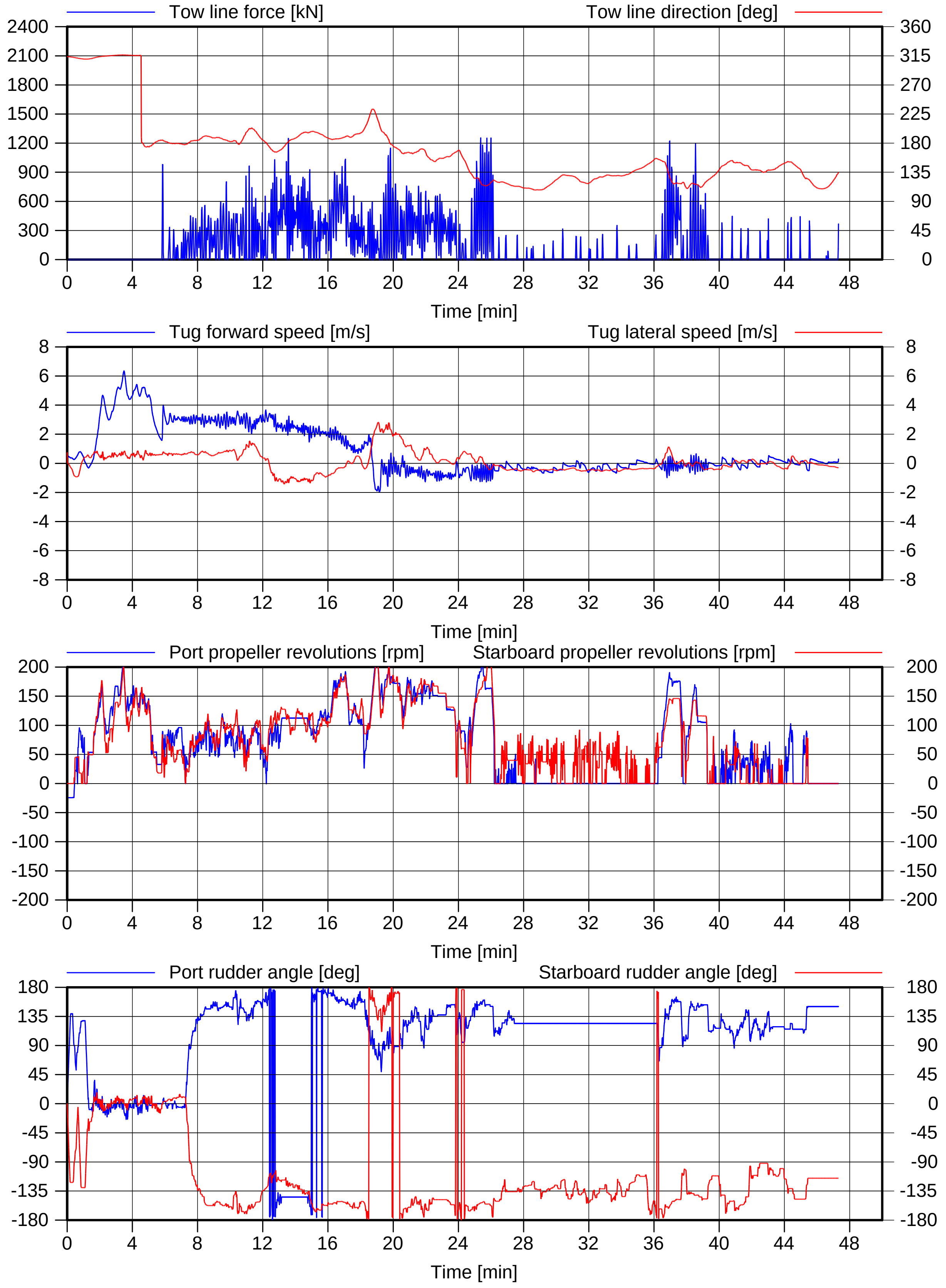
Run: 22	Malta
Arrival	Wind 12m/s from S
MARIN's Nautical Centre MSCN	Fig. 13.b



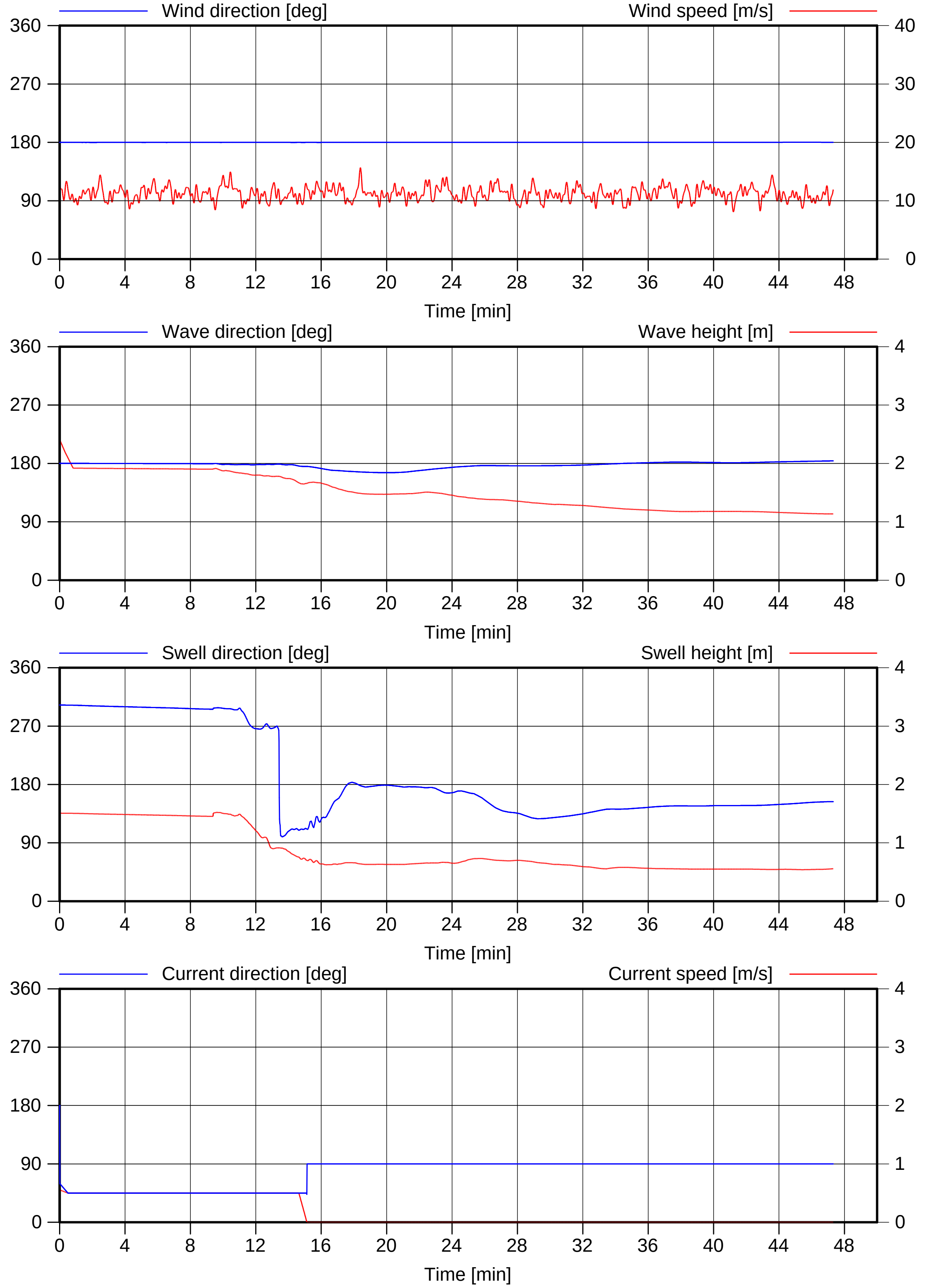
Run: 22	Malta
Arrival	Wind 12m/s from S
MARIN's Nautical Centre MSCN	Fig. 13.c



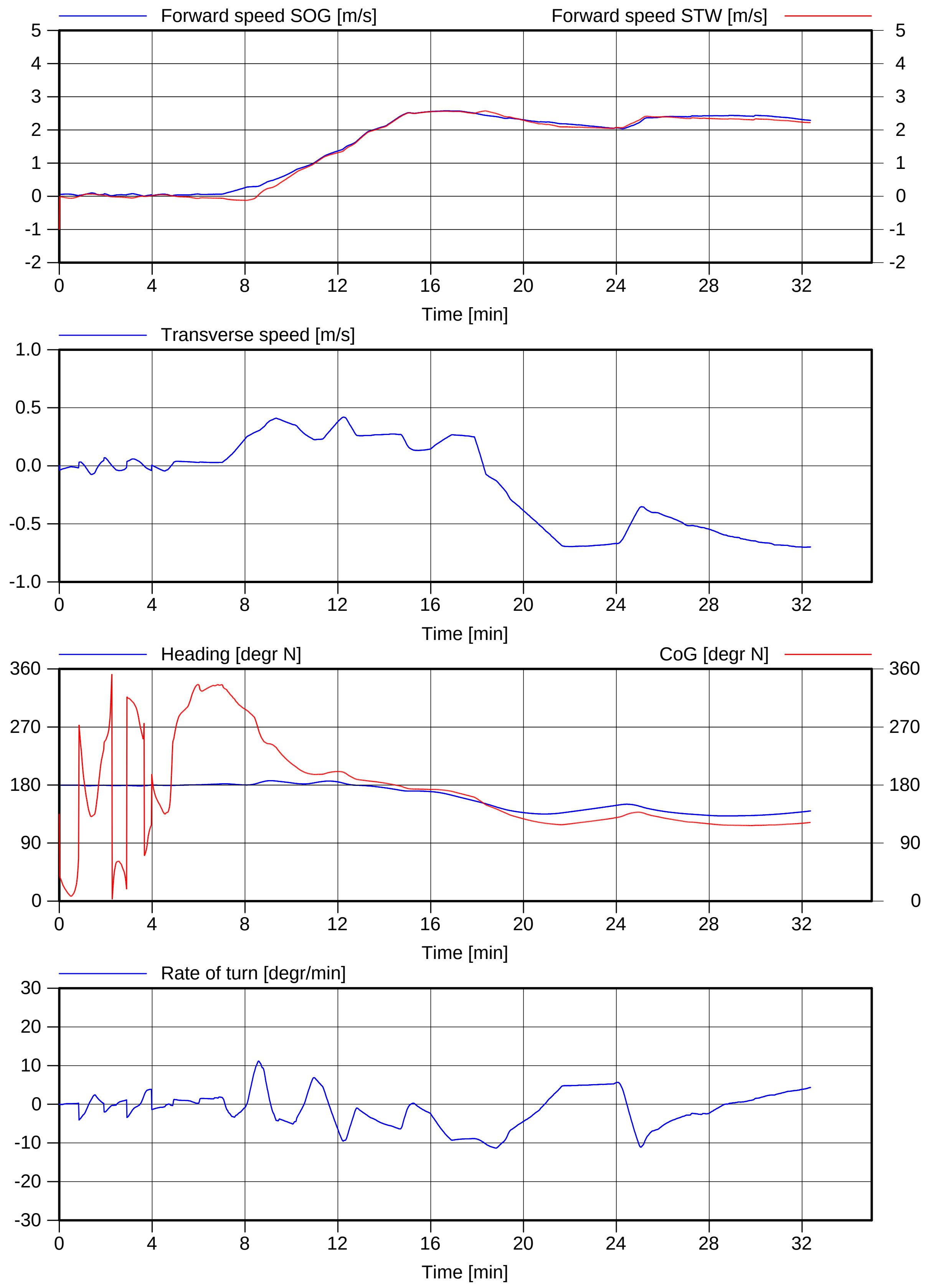
Run: 22	Malta
Arrival	Wind 12m/s from S
MARIN's Nautical Centre MSCN	Fig. 13.d



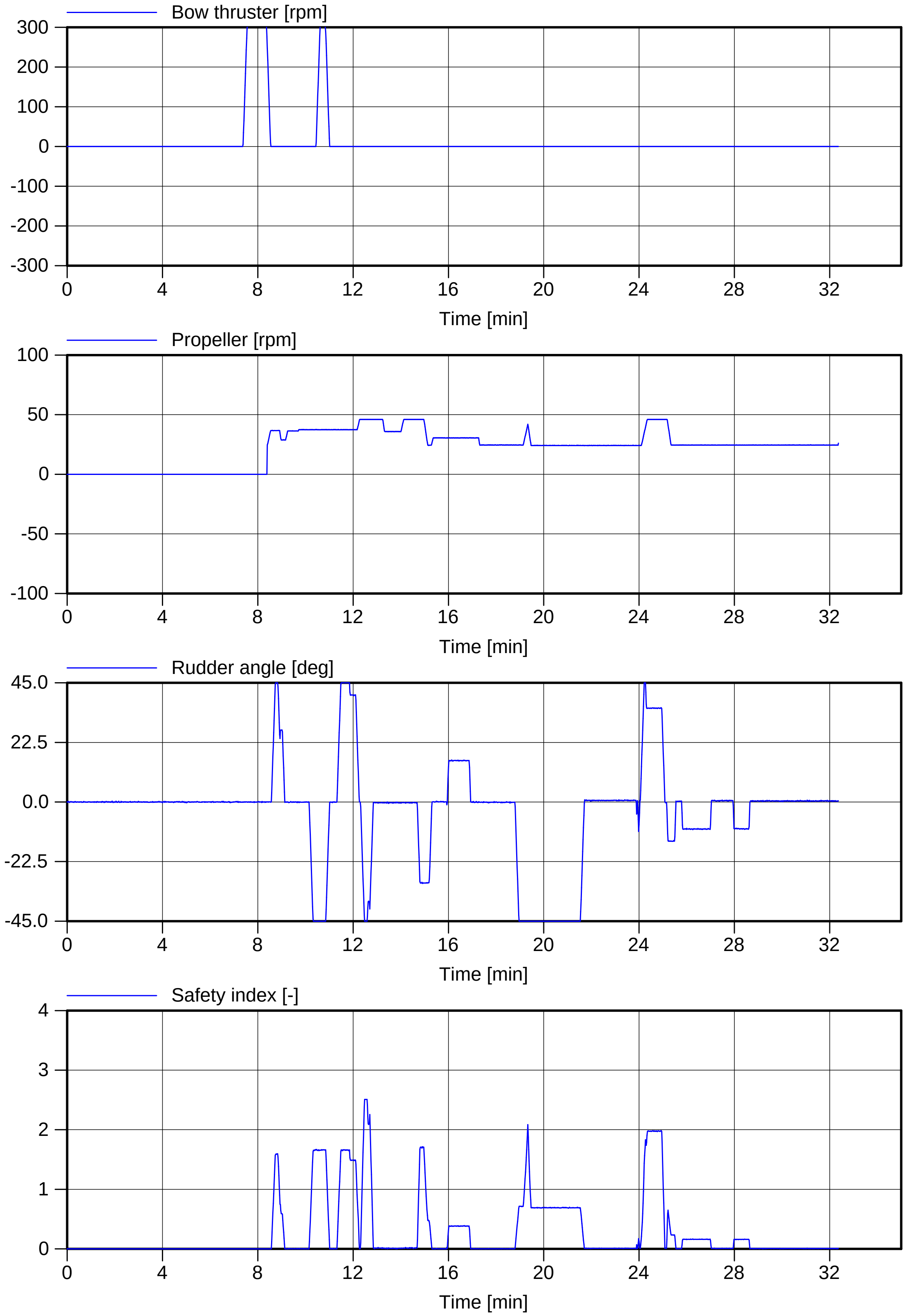
Run: 22	Malta
Arrival	Wind 12m/s from S
MARIN's Nautical Centre MSCN	Fig. 13.e



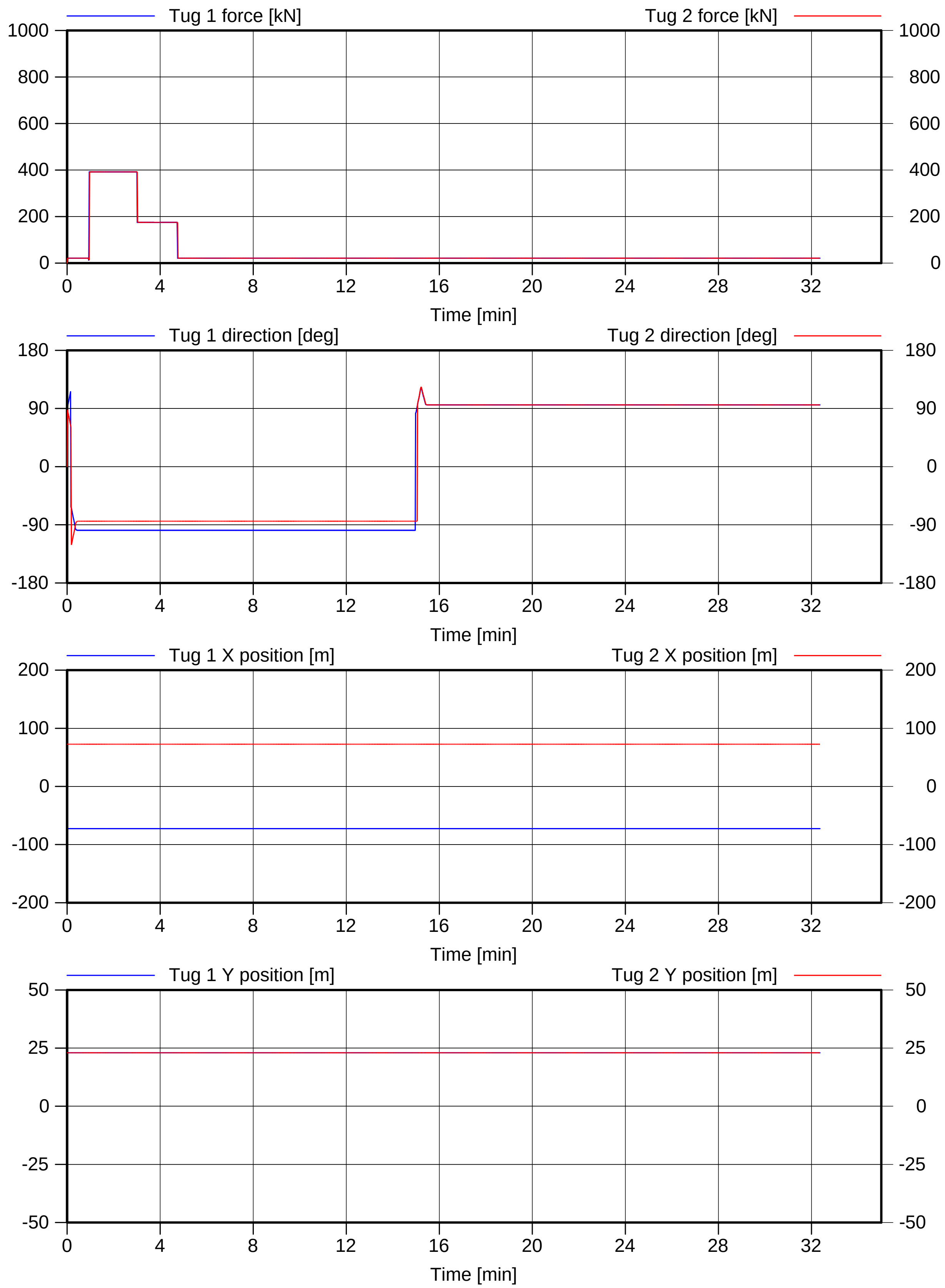
Run: 22	Malta
Arrival	Wind 12m/s from S
MARIN's Nautical Centre MSCN	Fig. 13.f



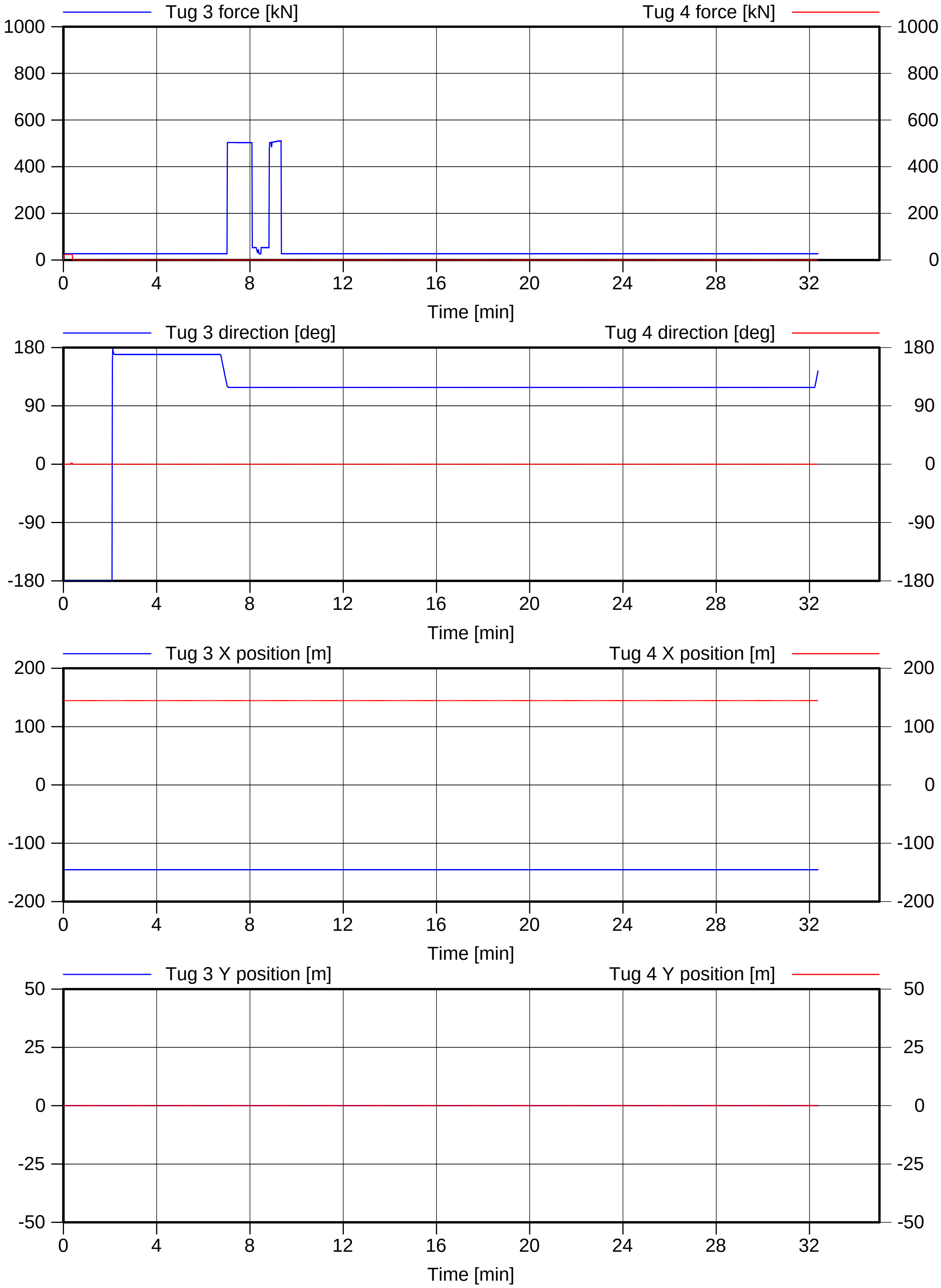
Run: 24	Malta
Departure	Wind 12m/s from SE
MARIN's Nautical Centre MSCN	Fig. 14.a



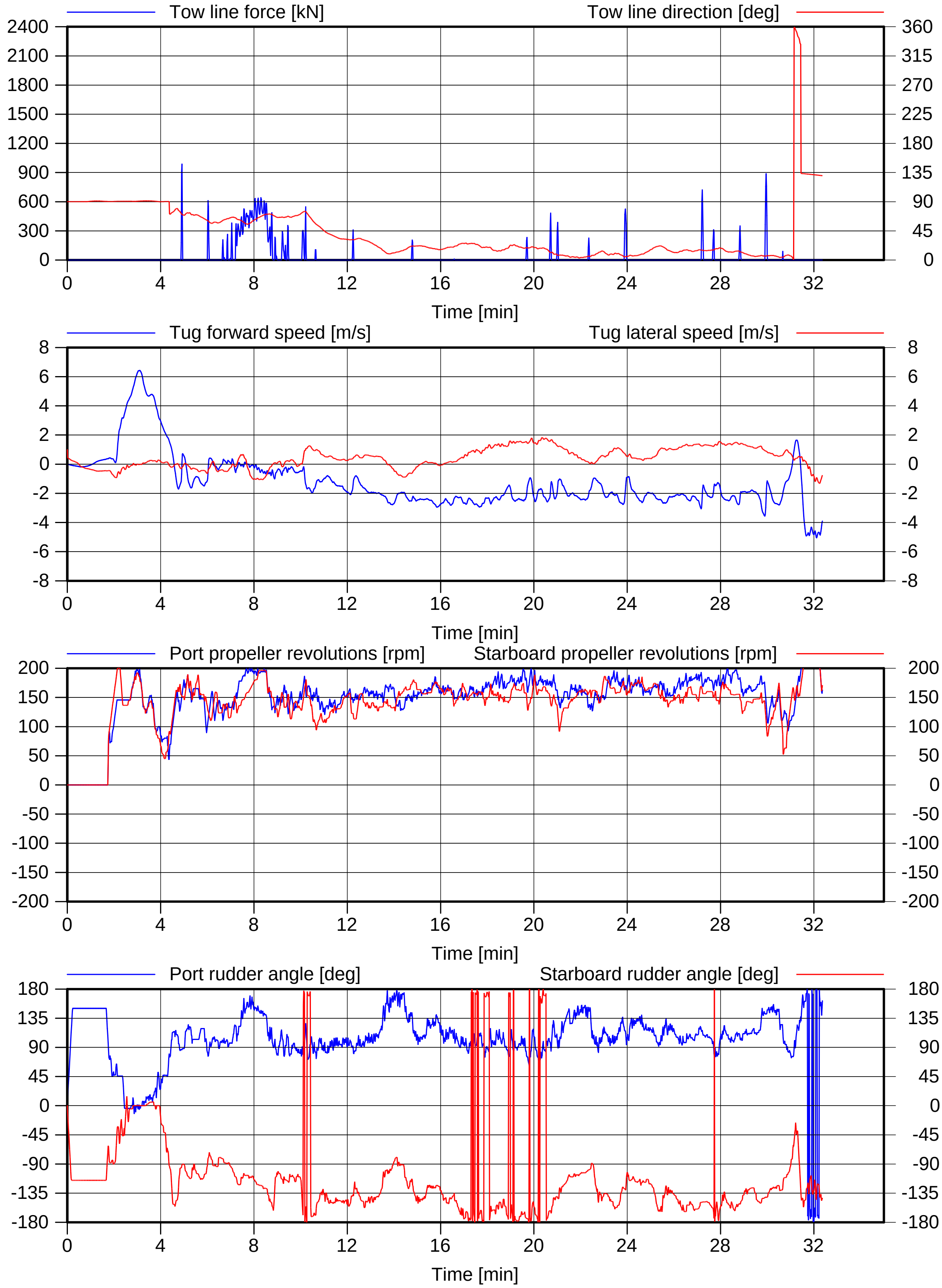
Run: 24	Malta
Departure	Wind 12m/s from SE
MARIN's Nautical Centre MSCN	Fig. 14.b



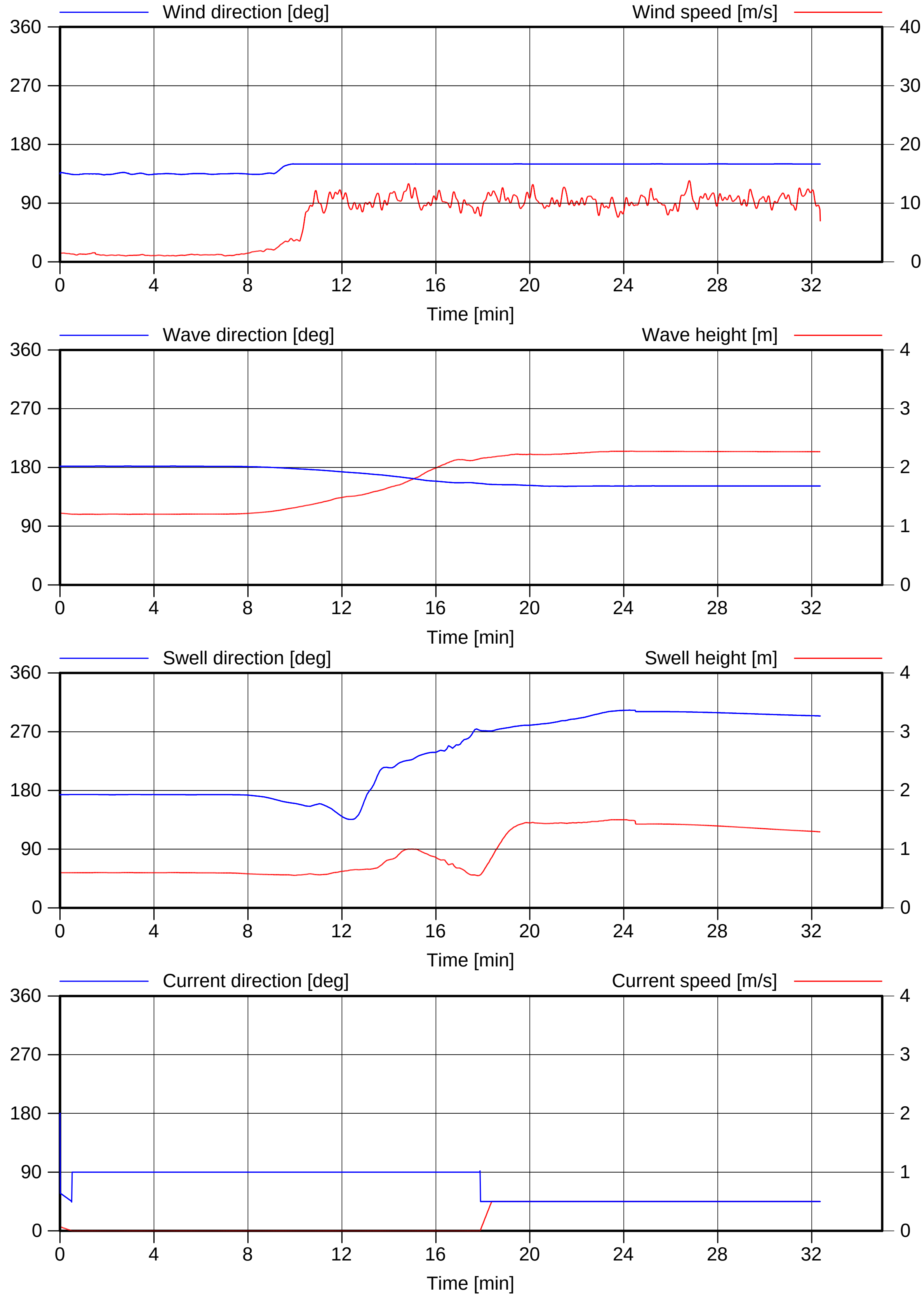
Run: 24	Malta
Departure	Wind 12m/s from SE
MARIN's Nautical Centre MSCN	Fig. 14.c



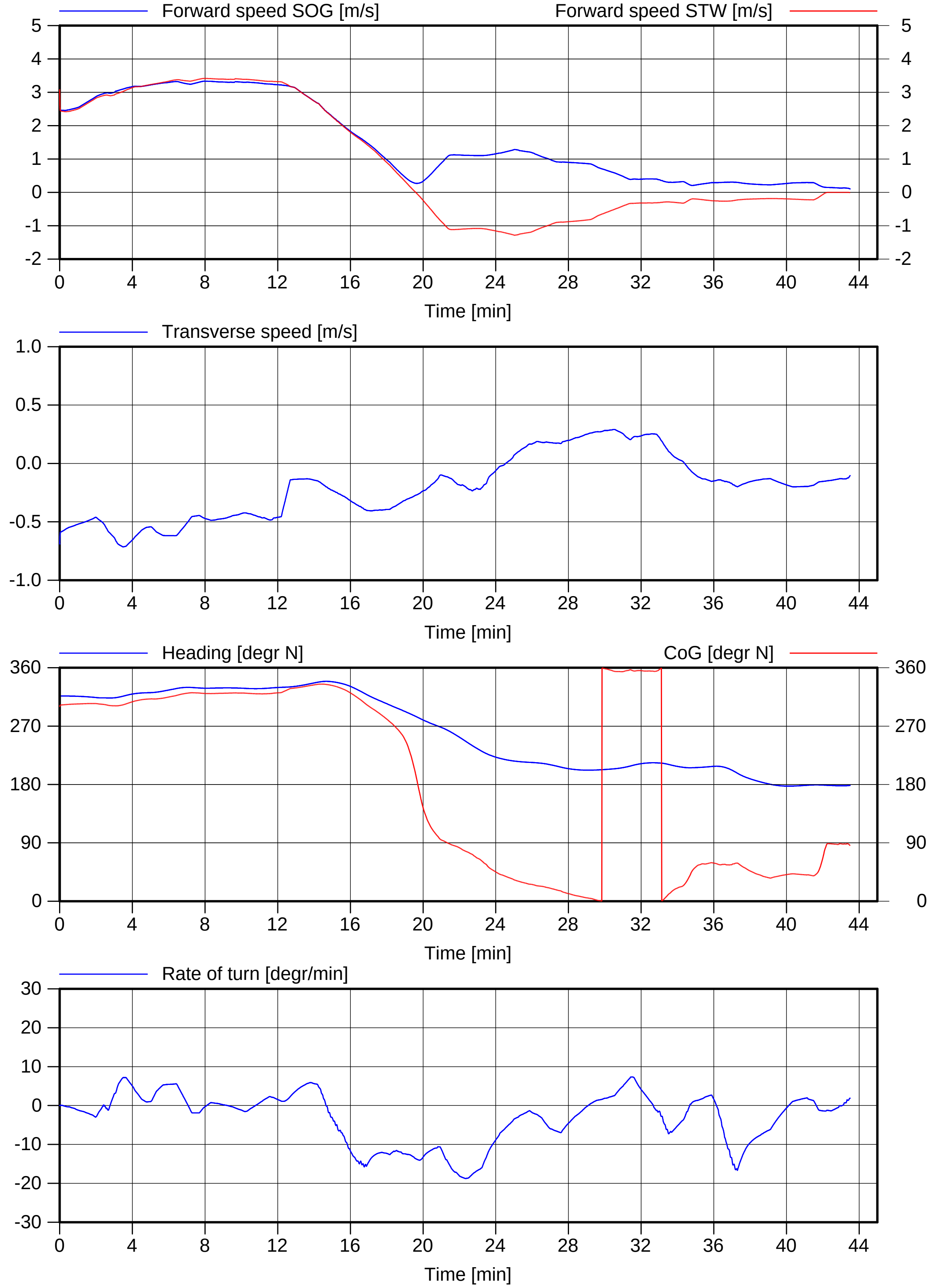
Run: 24	Malta
Departure	Wind 12m/s from SE
MARIN's Nautical Centre MSCN	Fig. 14.d



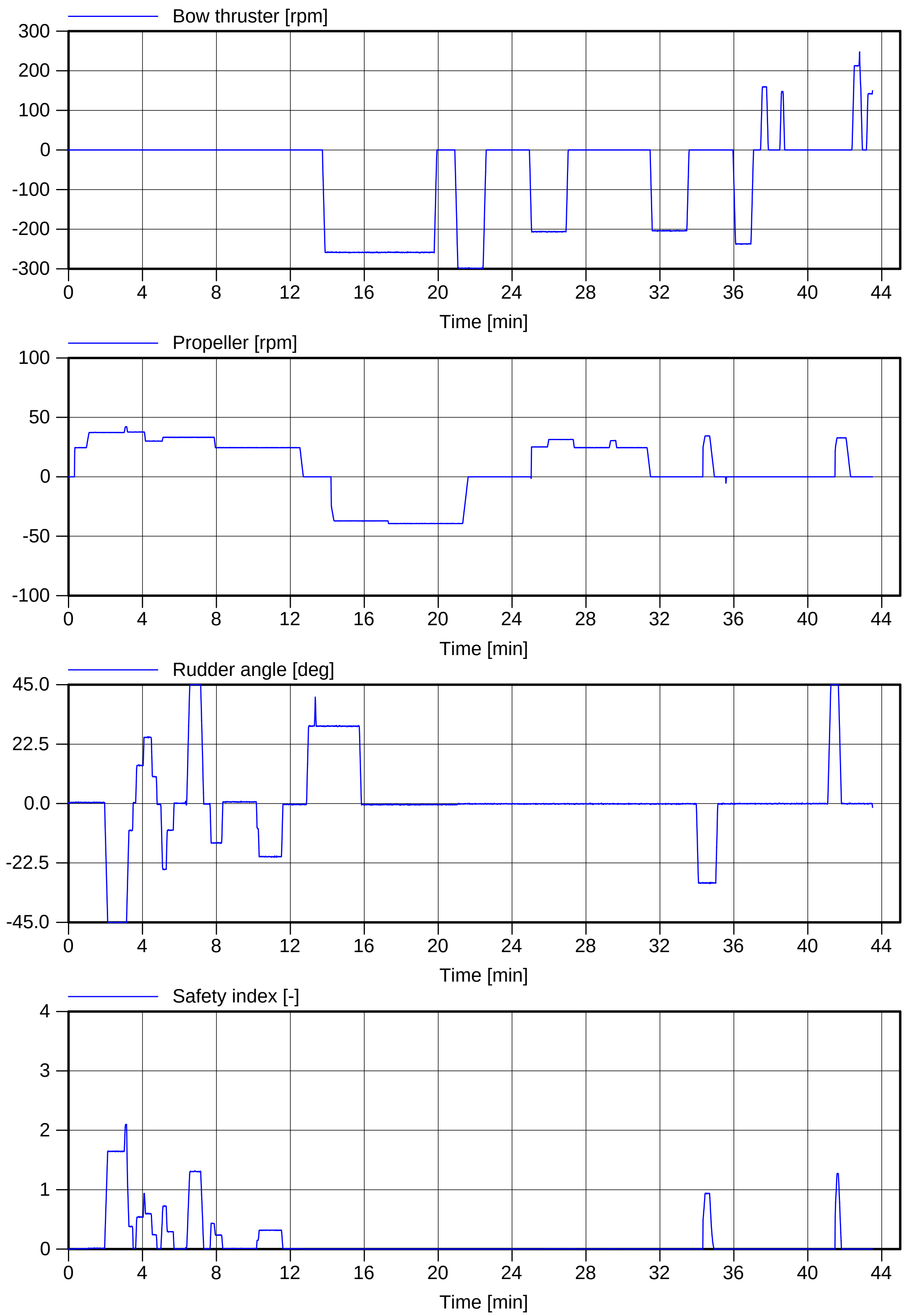
Run: 24	Malta
Departure	Wind 12m/s from SE
MARIN's Nautical Centre MSCN	Fig. 14.e



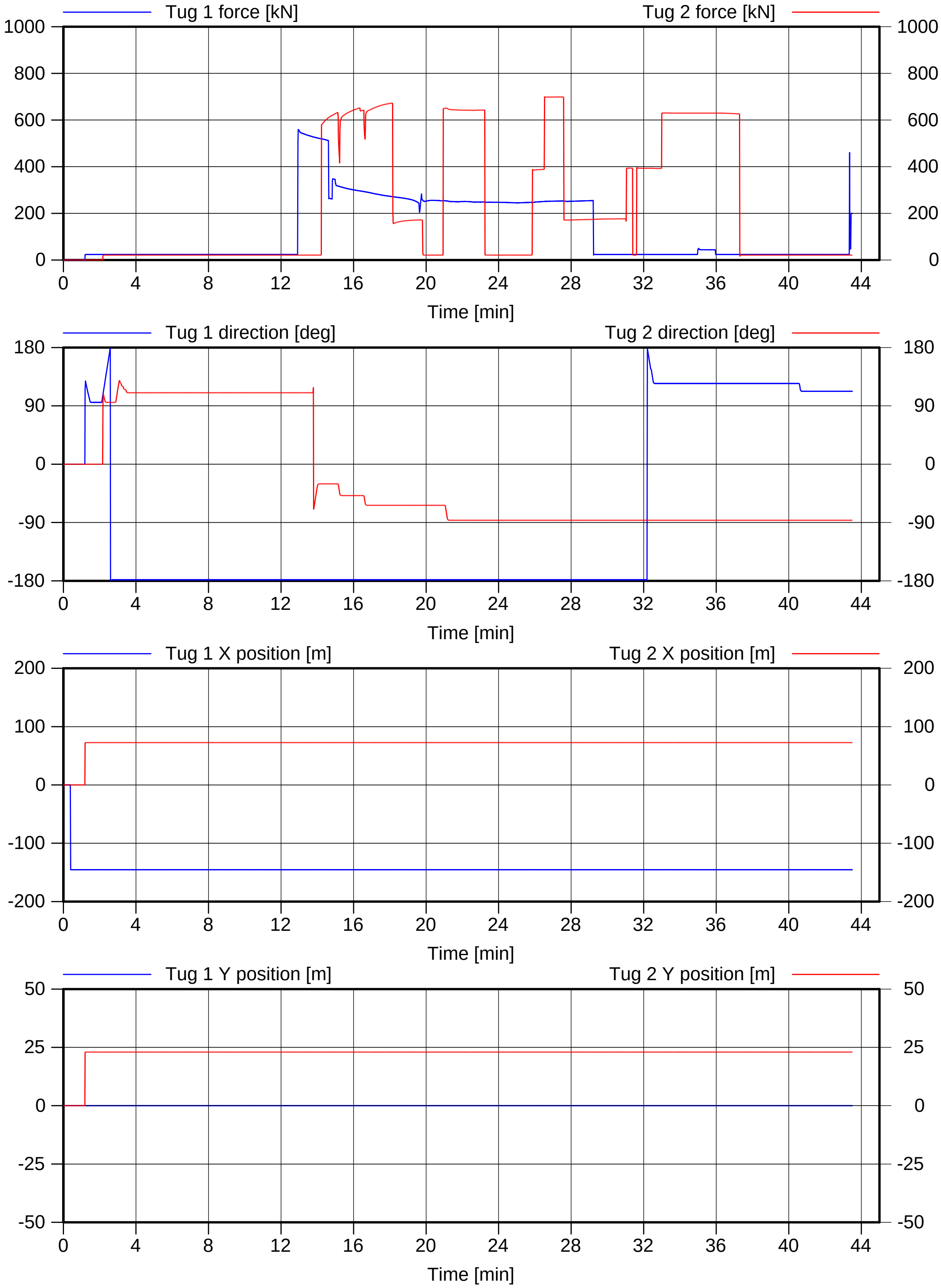
Run: 24	Malta
Departure	Wind 12m/s from SE
MARIN's Nautical Centre MSCN	Fig. 14.f



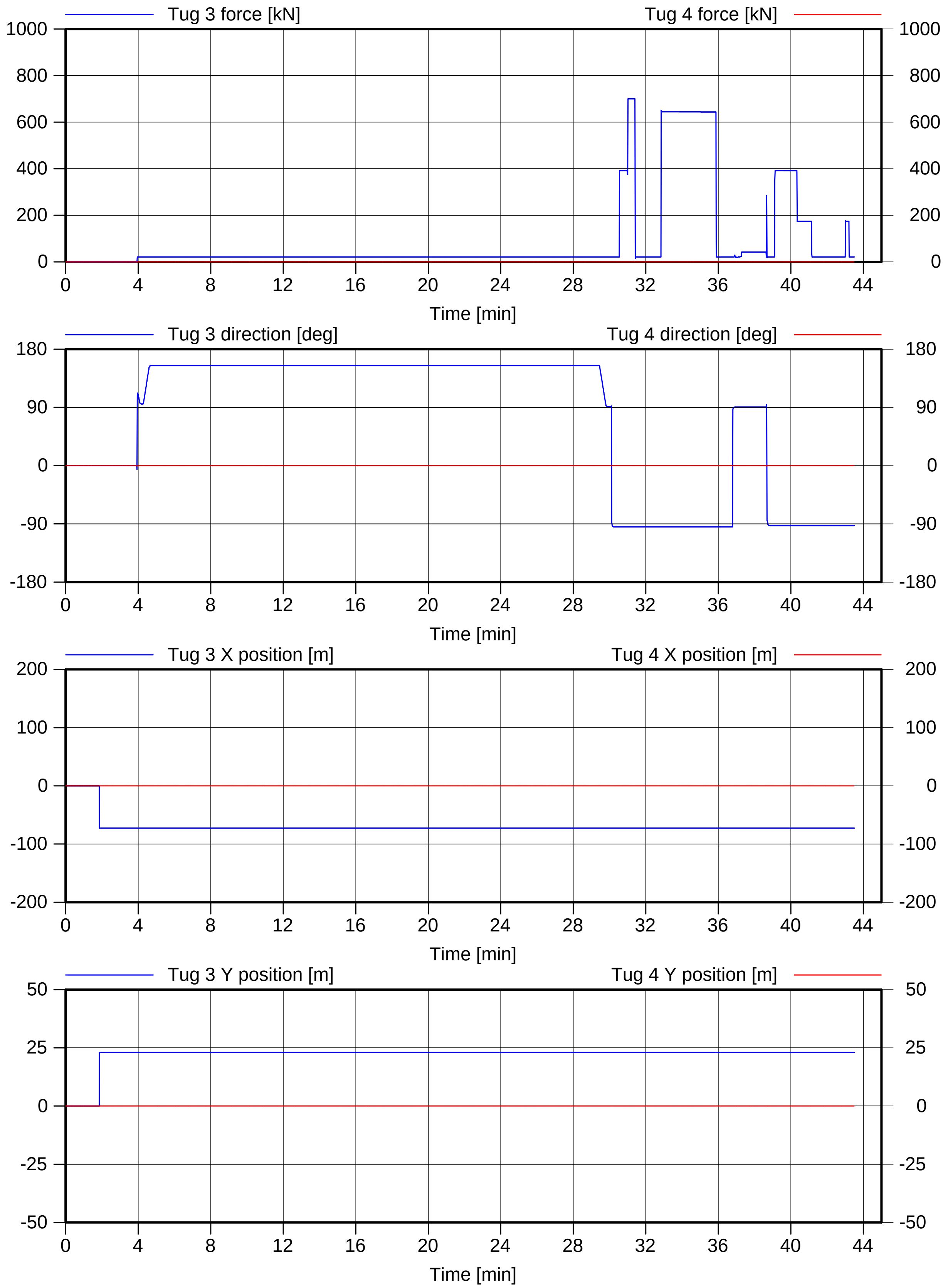
Run: 25	Malta
Arrival	Wind 12m/s from SE
MARIN's Nautical Centre MSCN	Fig. 15.a



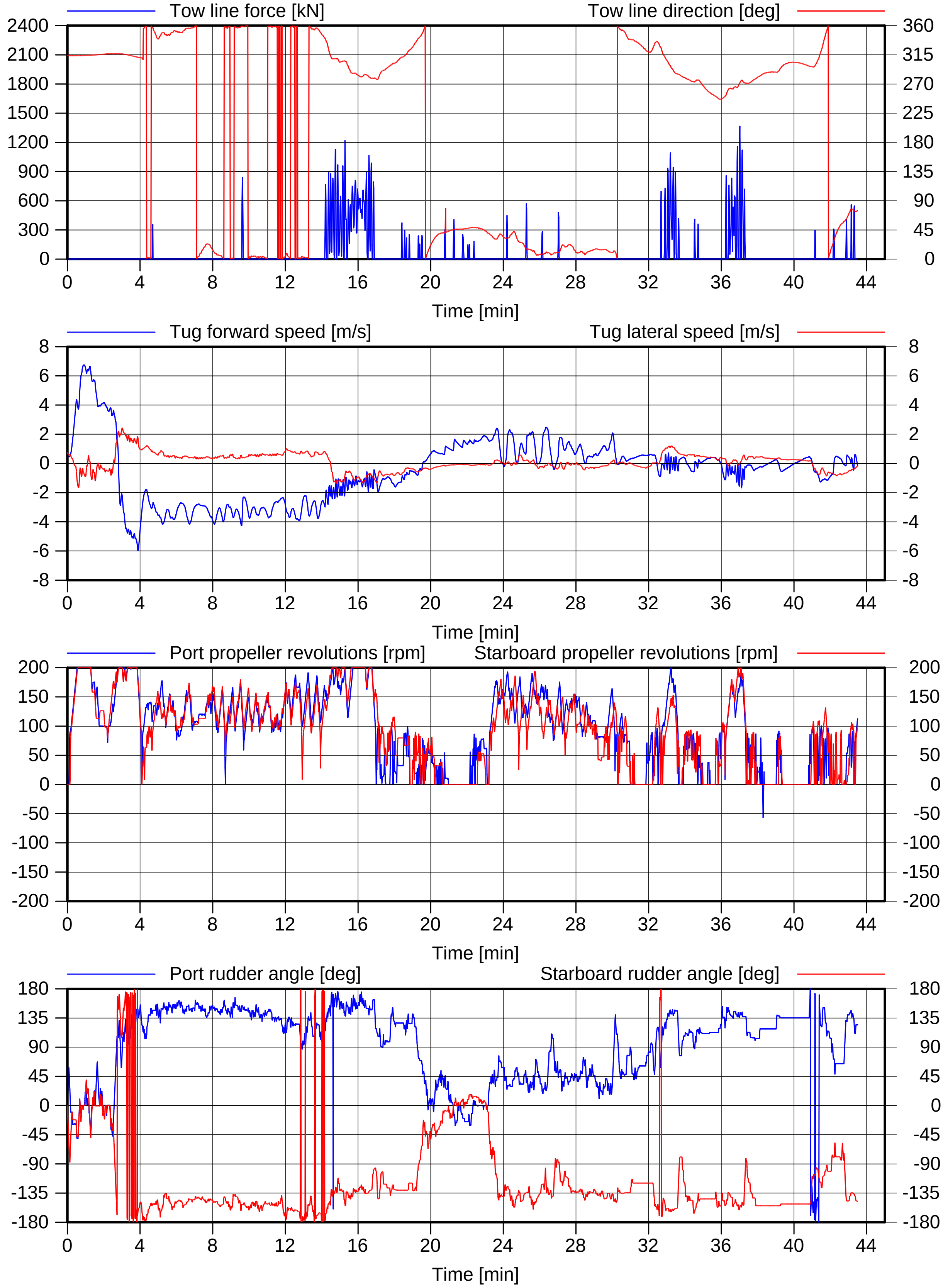
Run: 25	Malta
Arrival	Wind 12m/s from SE
MARIN's Nautical Centre MSCN	Fig. 15.b



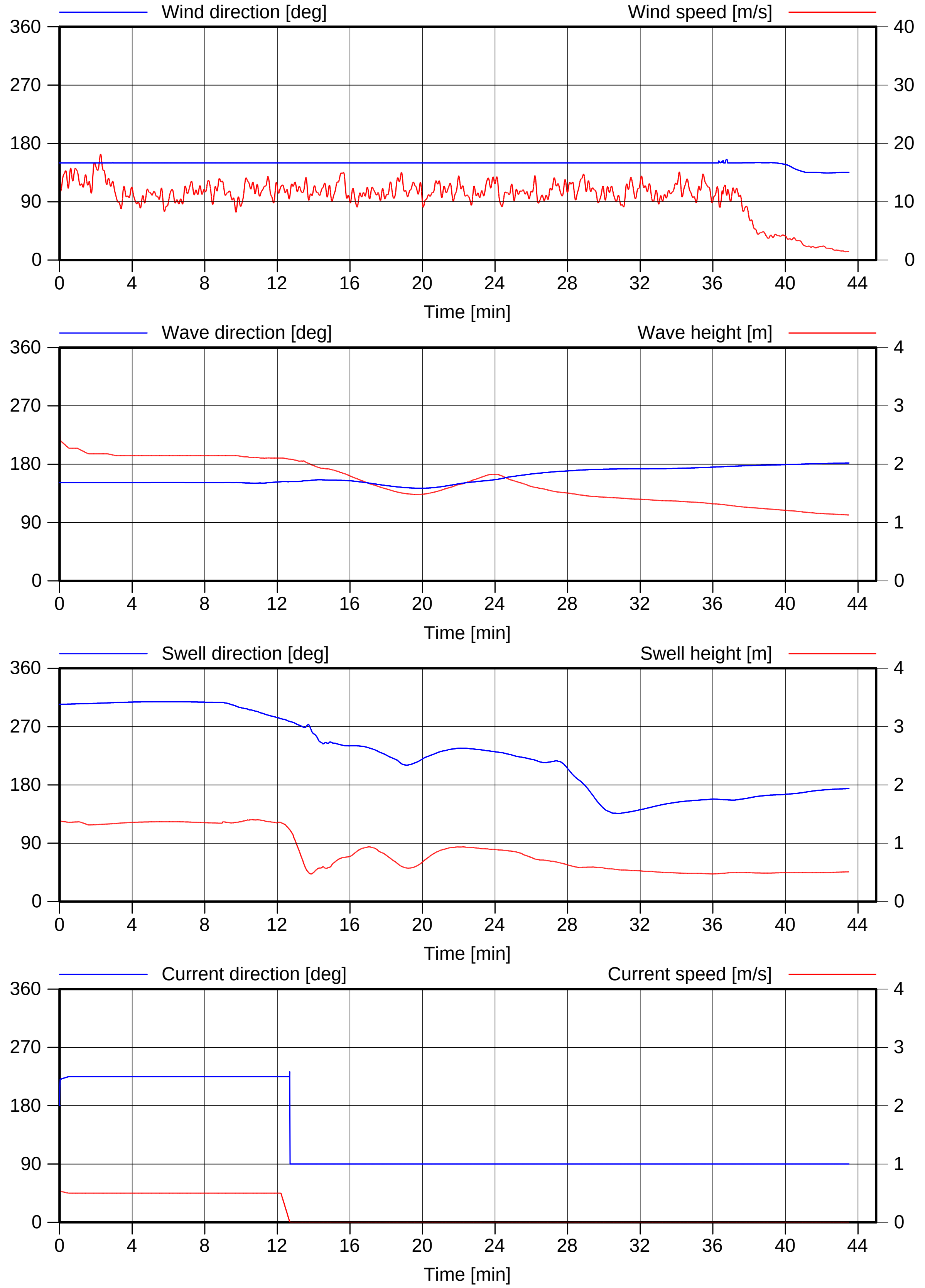
Run: 25	Malta
Arrival	Wind 12m/s from SE
MARIN's Nautical Centre MSCN	Fig. 15.c



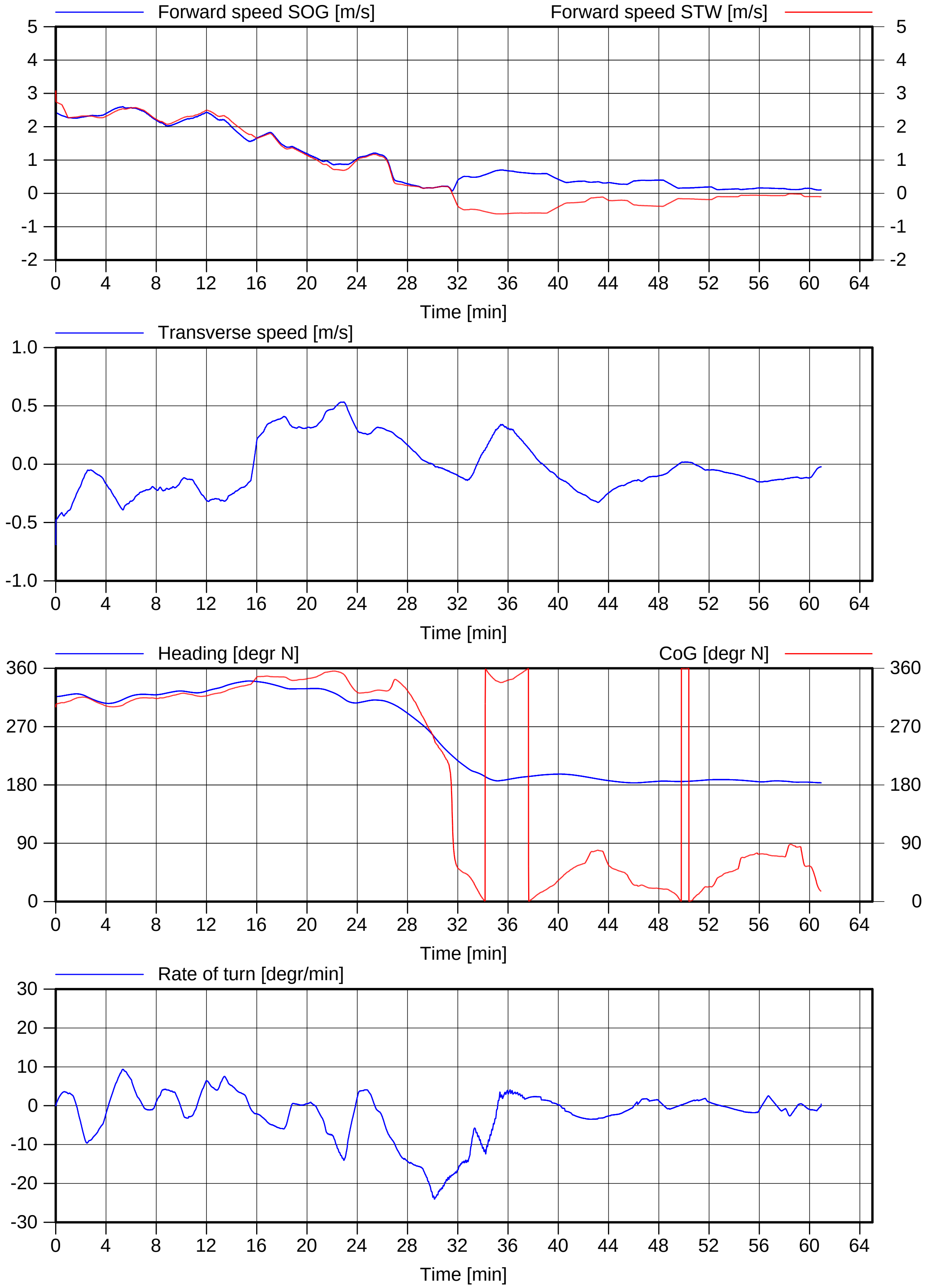
Run: 25	Malta
Arrival	Wind 12m/s from SE
MARIN's Nautical Centre MSCN	Fig. 15.d



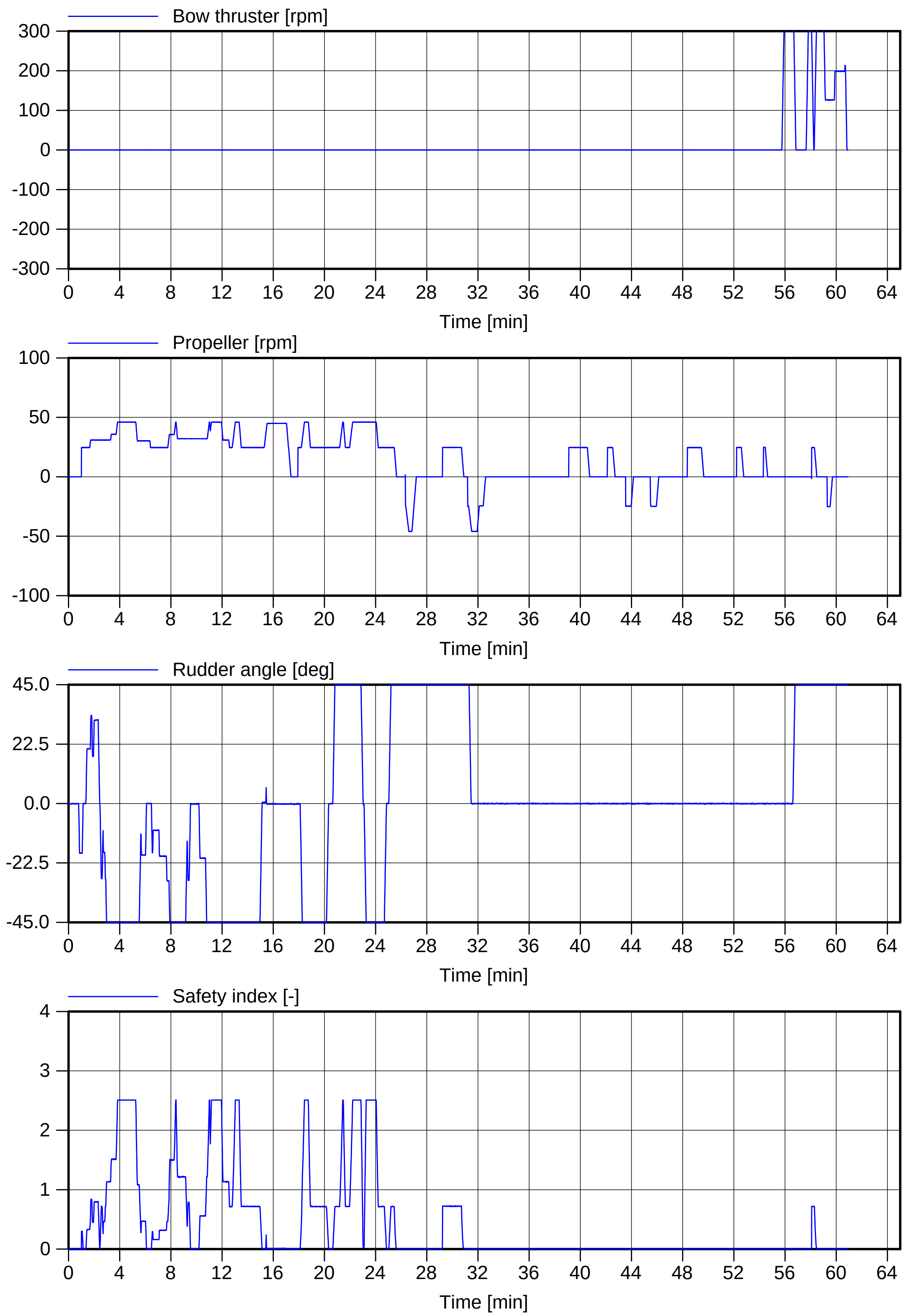
Run: 25	Malta
Arrival	Wind 12m/s from SE
MARIN's Nautical Centre MSCN	Fig. 15.e



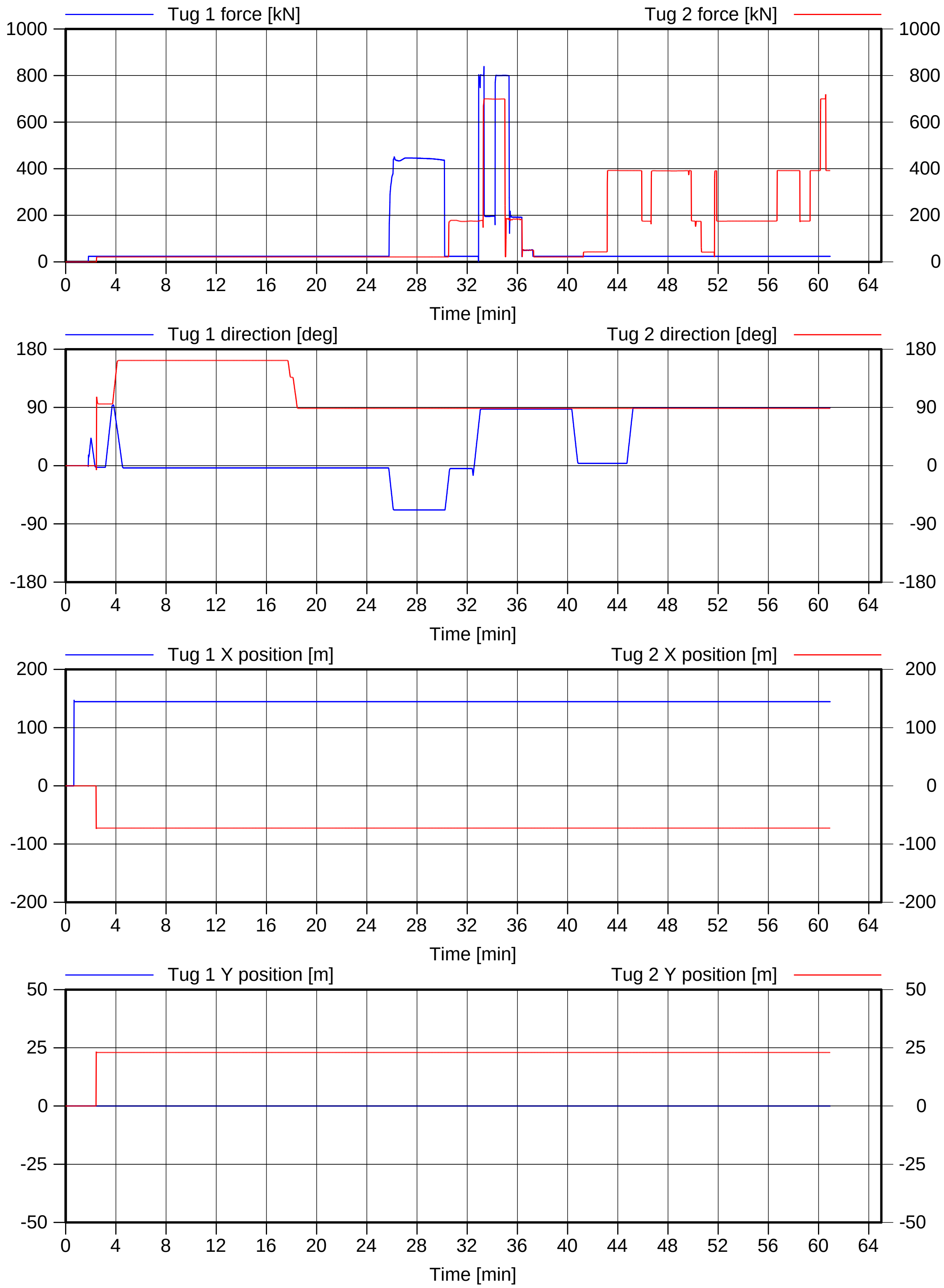
Run: 25	Malta
Arrival	Wind 12m/s from SE
MARIN's Nautical Centre MSCN	Fig. 15.f



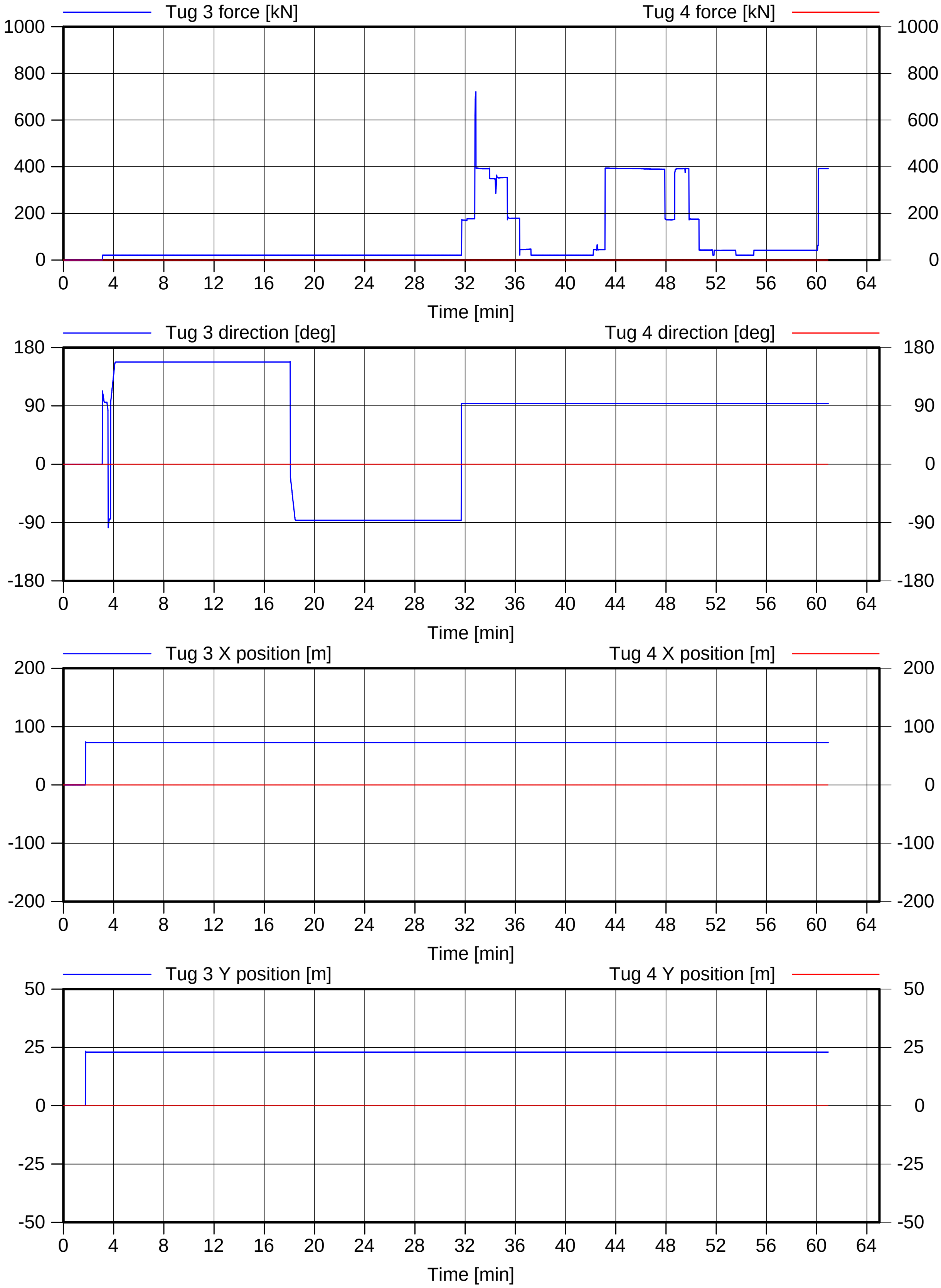
Run: 27	Malta
Arrival	Wind 12m/s from W
MARIN's Nautical Centre MSCN	Fig. 16.a



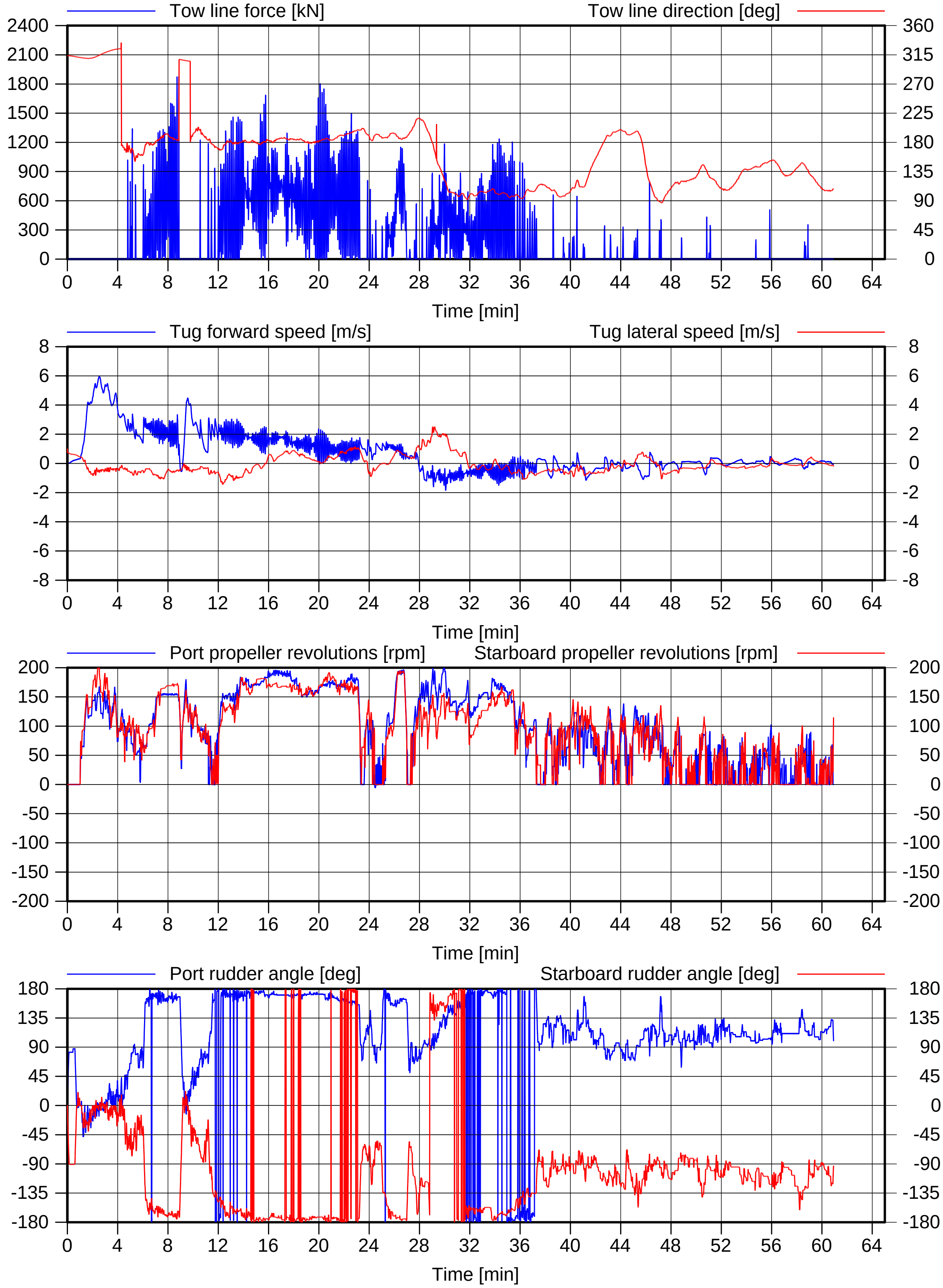
Run: 27	Malta
Arrival	Wind 12m/s from W
MARIN's Nautical Centre MSCN	Fig. 16.b



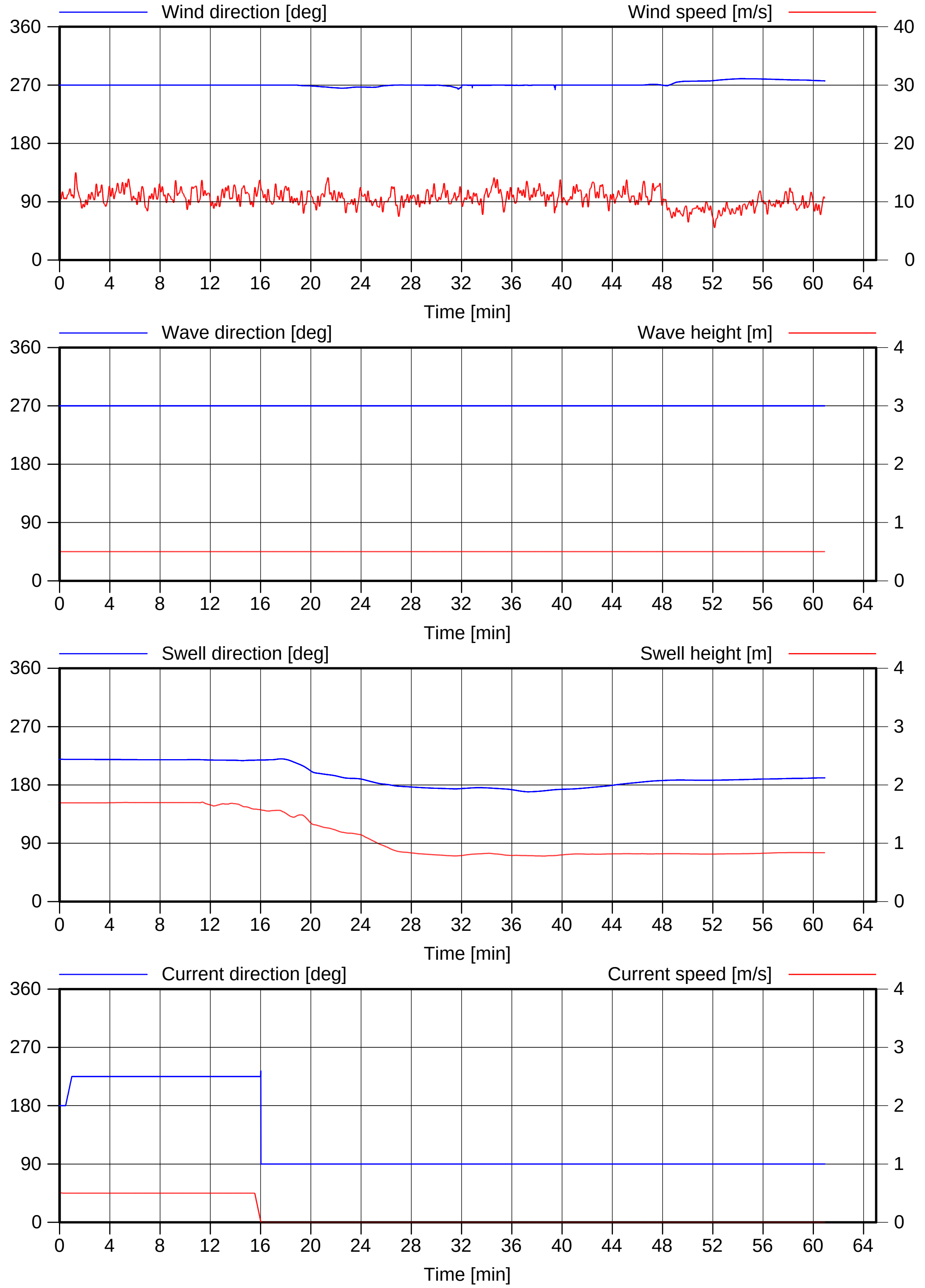
Run: 27	Malta
Arrival	Wind 12m/s from W
MARIN's Nautical Centre MSCN	Fig. 16.c



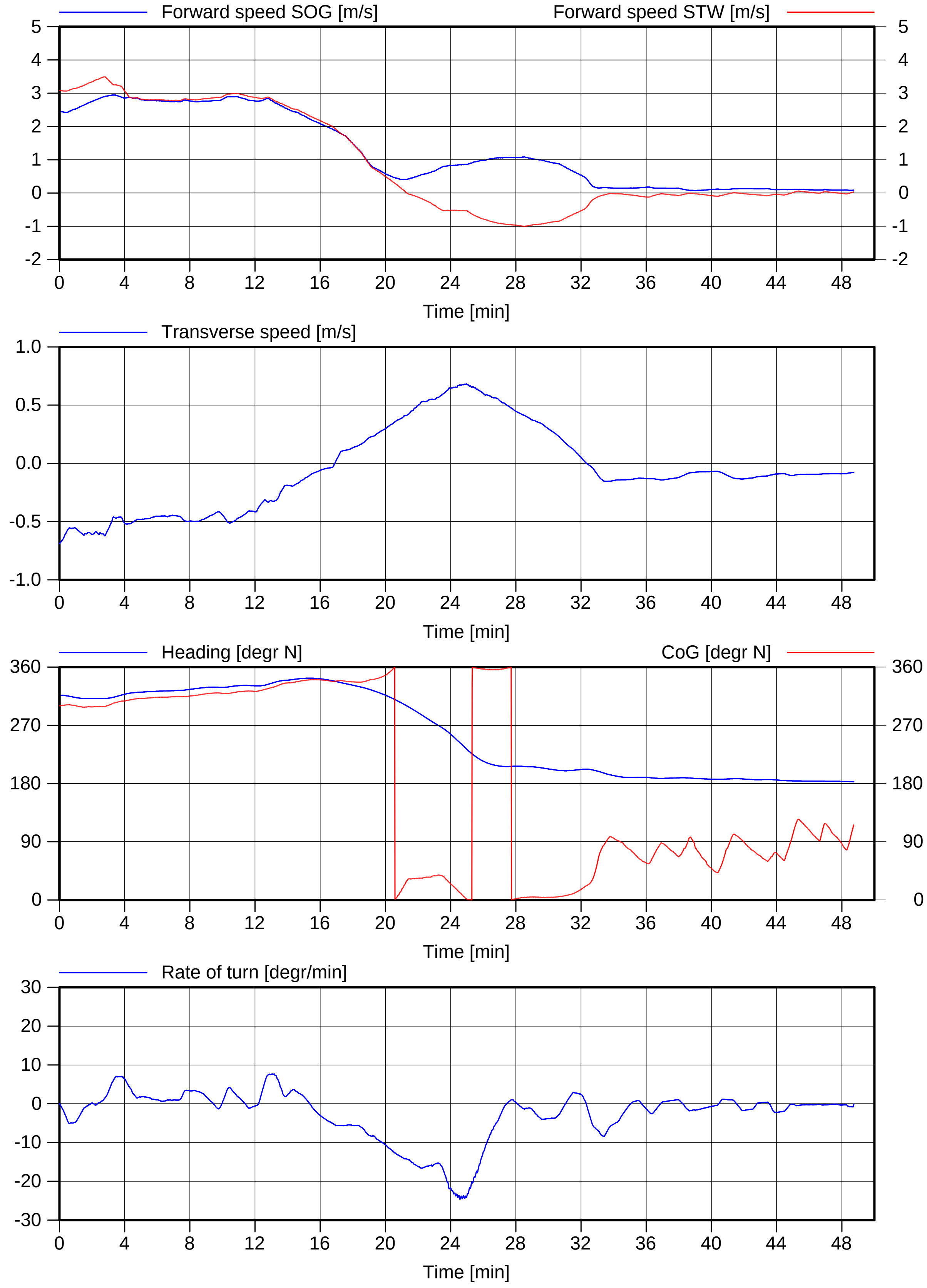
Run: 27	Malta
Arrival	Wind 12m/s from W
MARIN's Nautical Centre MSCN	Fig. 16.d



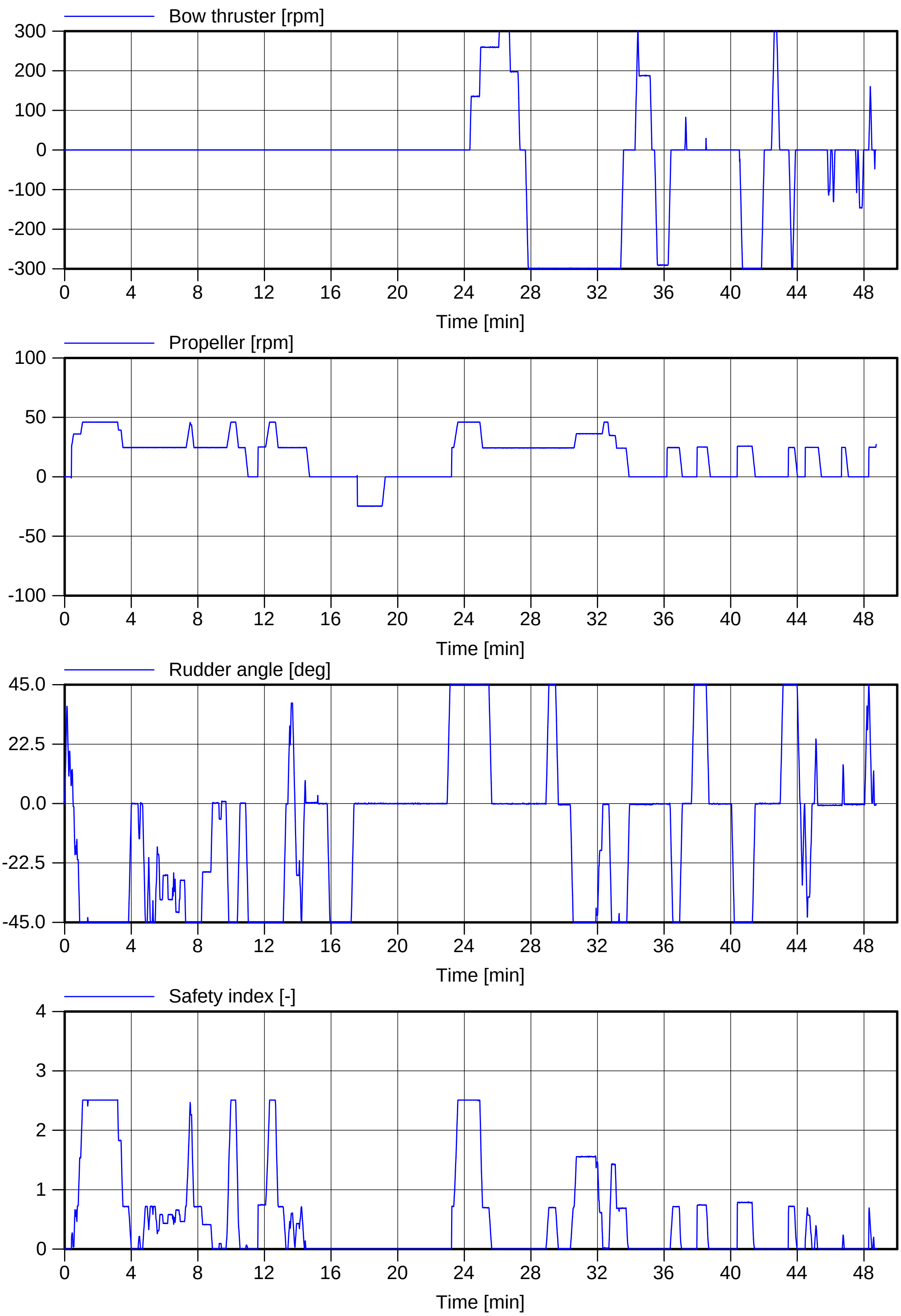
Run: 27	Malta
Arrival	Wind 12m/s from W
MARIN's Nautical Centre MSCN	Fig. 16.e



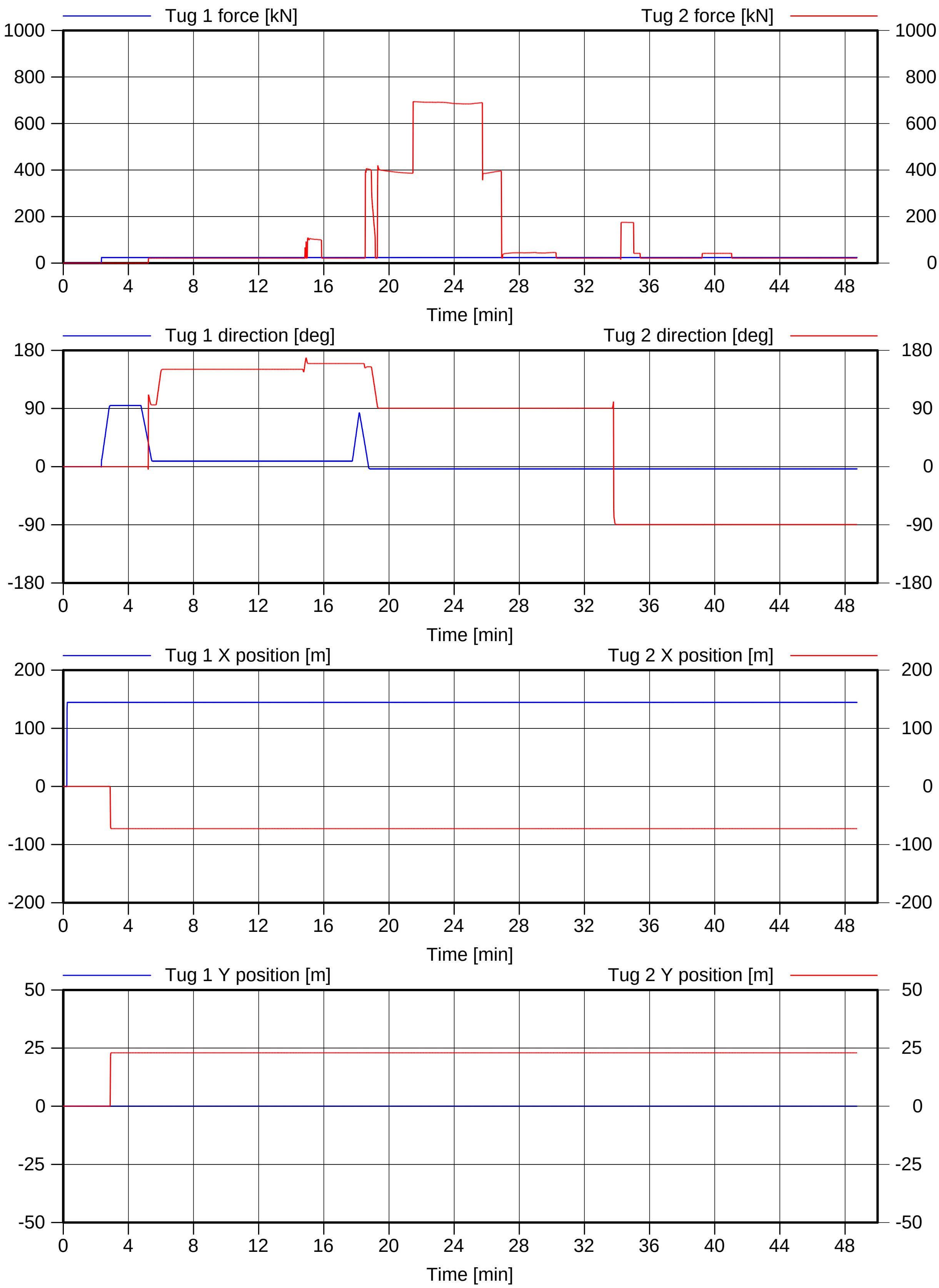
Run: 27	Malta
Arrival	Wind 12m/s from W
MARIN's Nautical Centre MSCN	Fig. 16.f



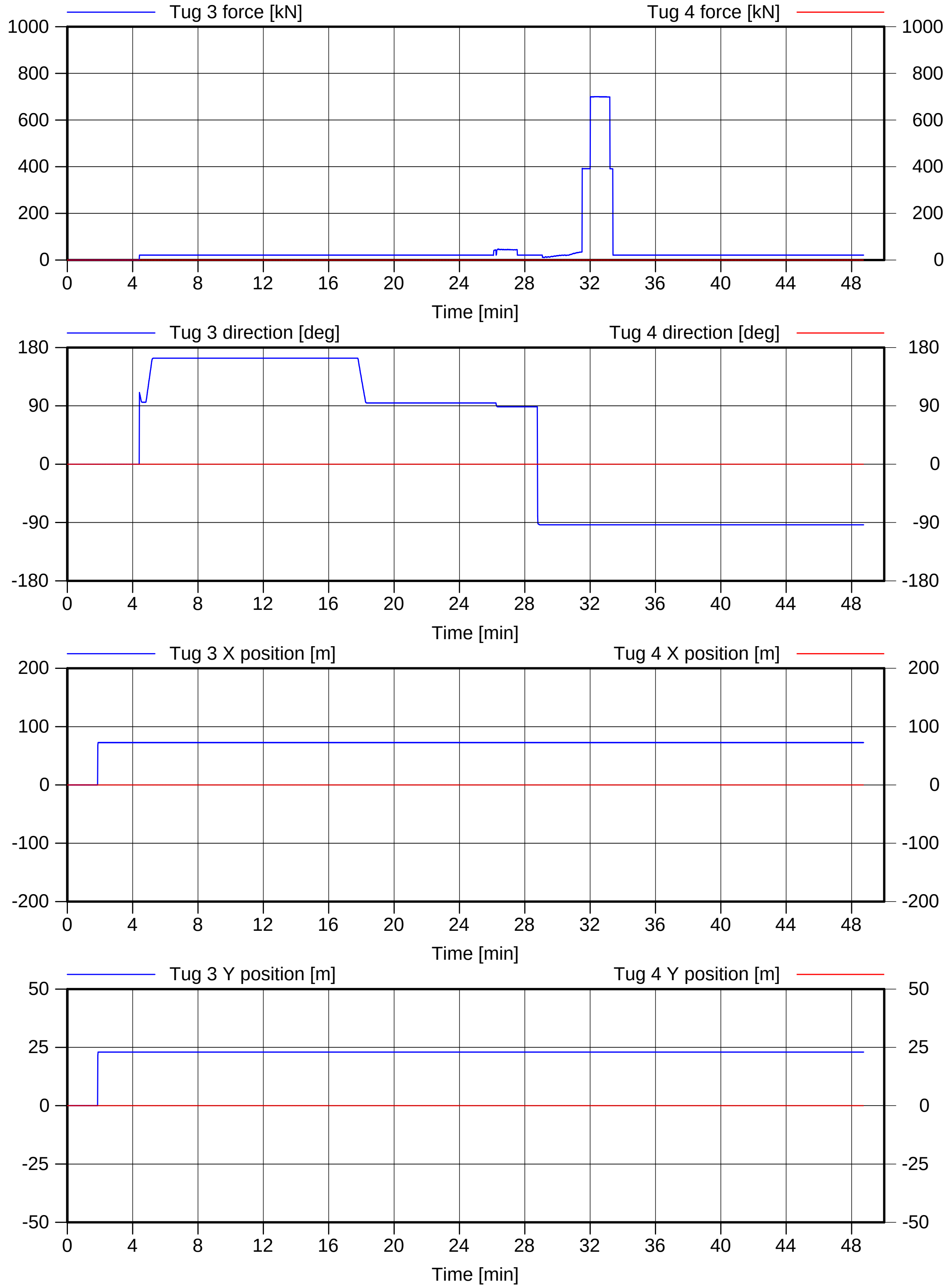
Run: 28	Malta
Arrival	Wind 12m/s from S
MARIN's Nautical Centre MSCN	Fig. 17.a



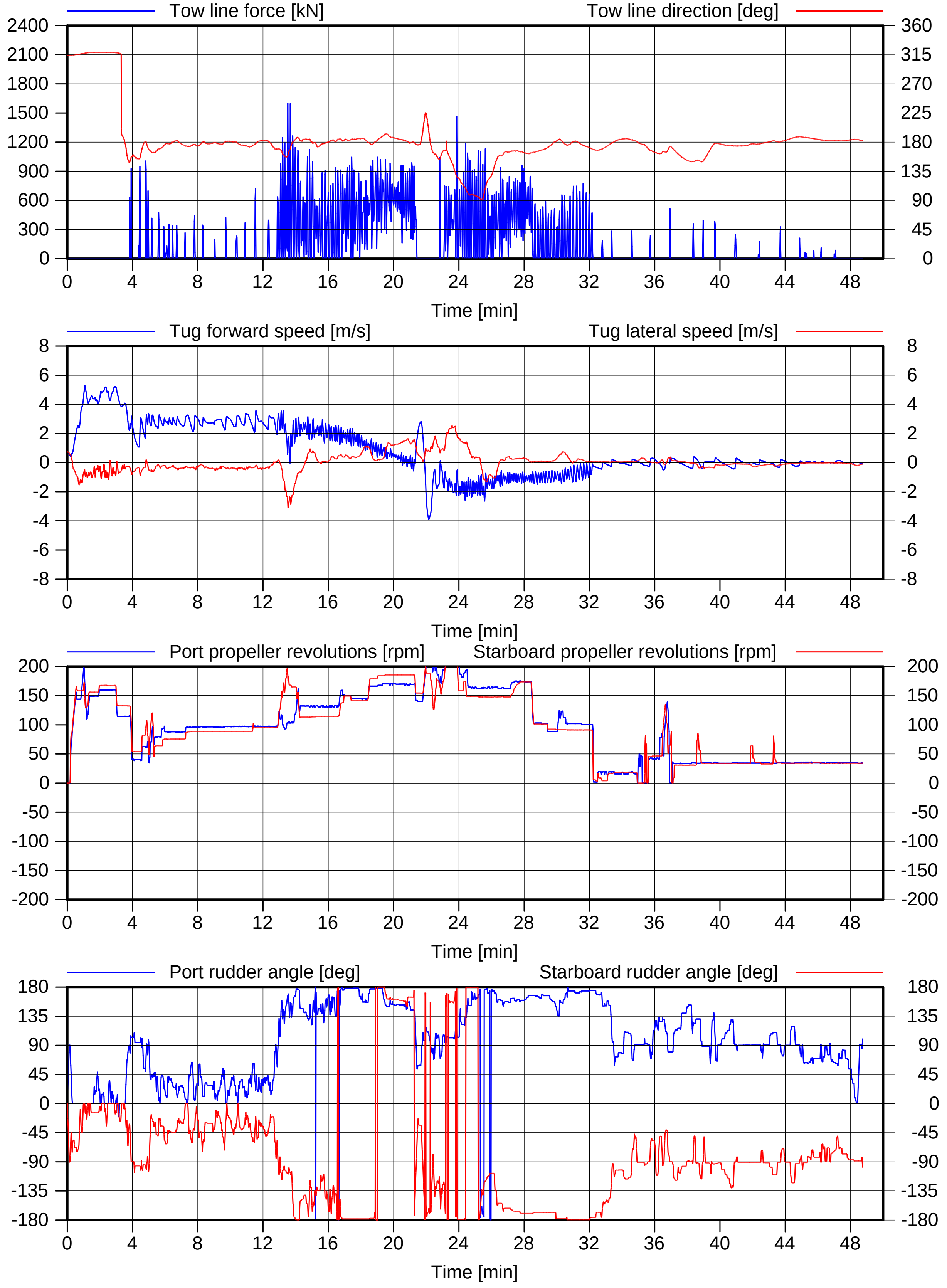
Run: 28	Malta
Arrival	Wind 12m/s from S
MARIN's Nautical Centre MSCN	Fig. 17.b



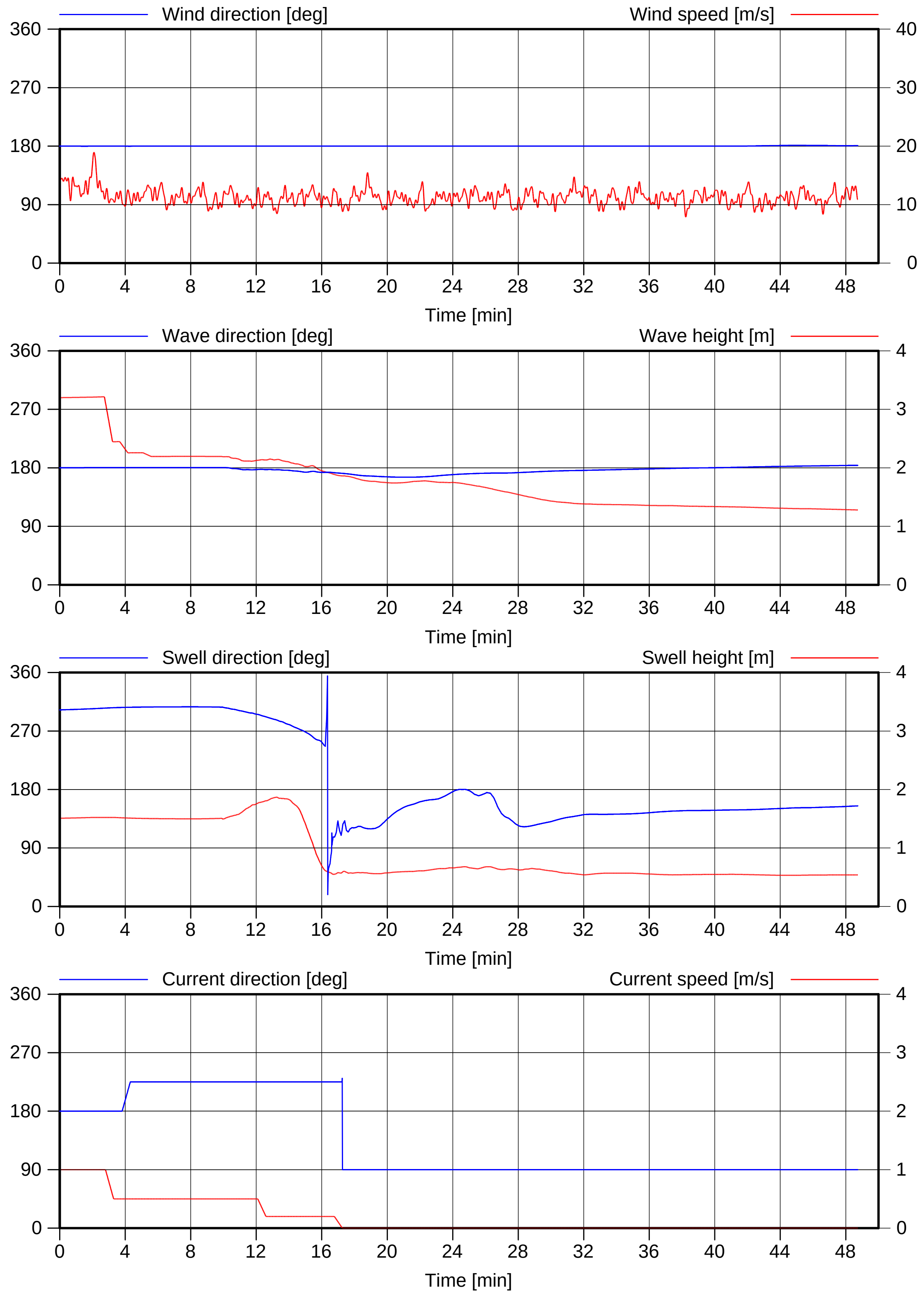
Run: 28	Malta
Arrival	Wind 12m/s from S
MARIN's Nautical Centre MSCN	Fig. 17.c



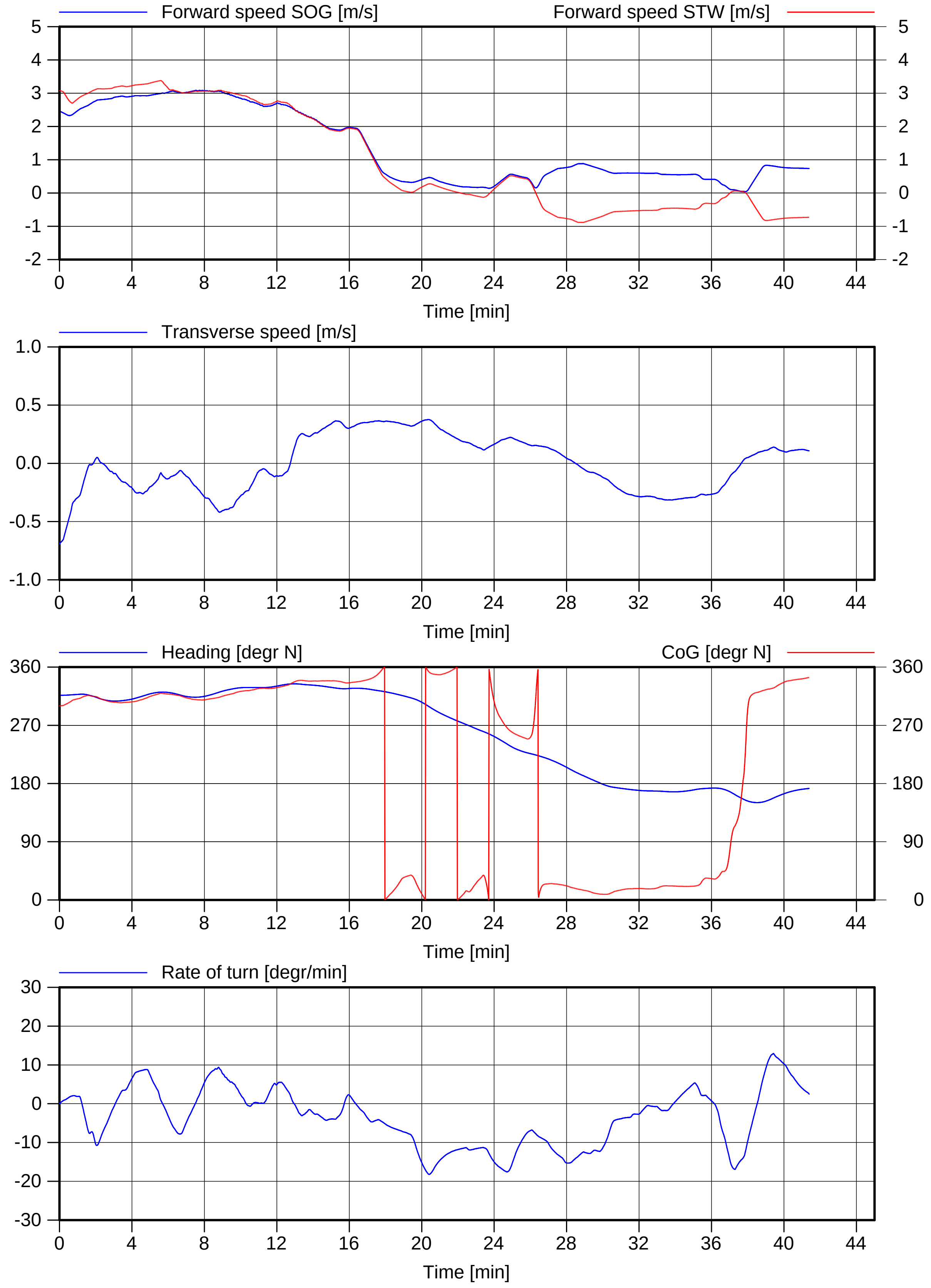
Run: 28	Malta
Arrival	Wind 12m/s from S
MARIN's Nautical Centre MSCN	Fig. 17.d



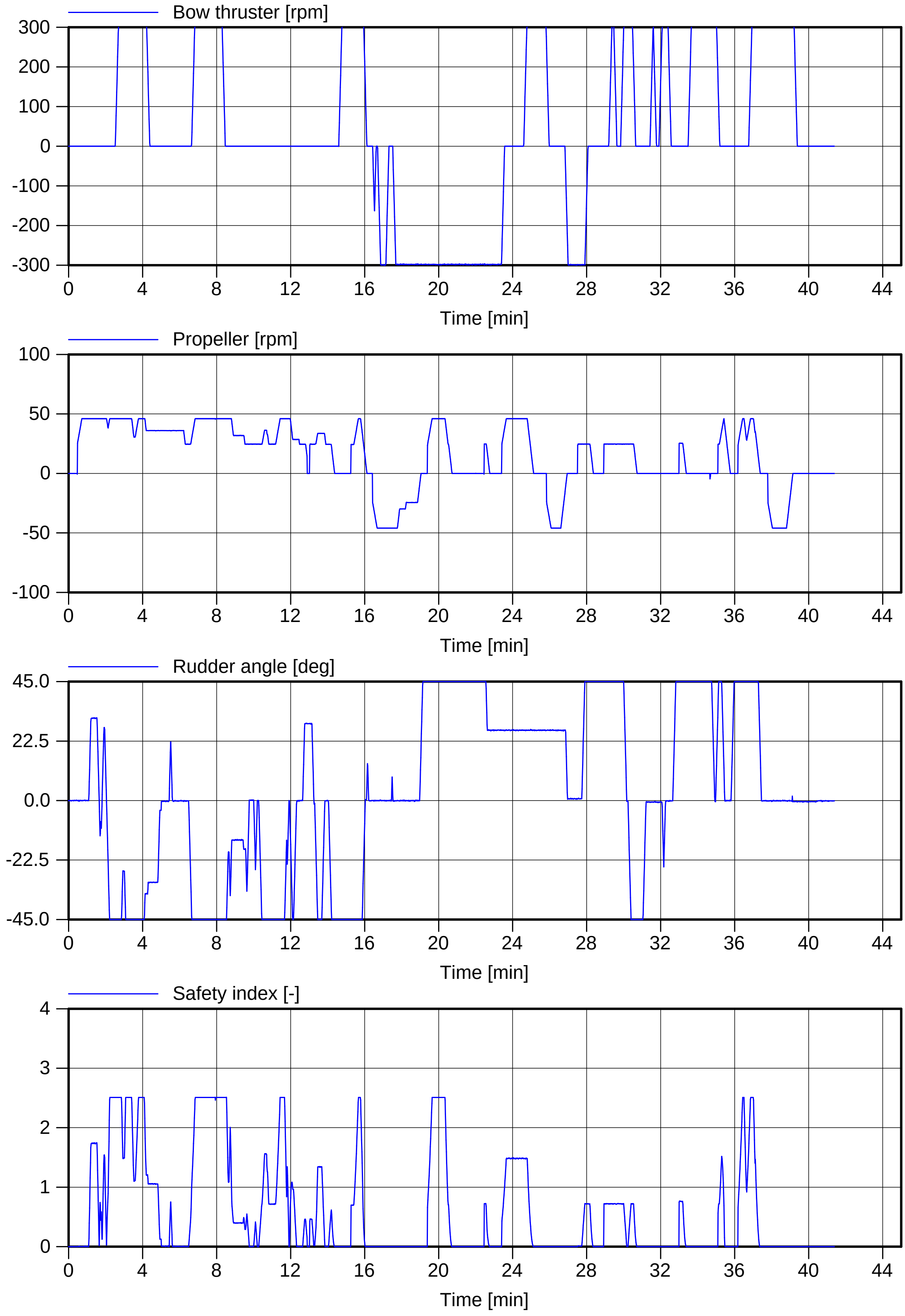
Run: 28	Malta
Arrival	Wind 12m/s from S
MARIN's Nautical Centre MSCN	Fig. 17.e



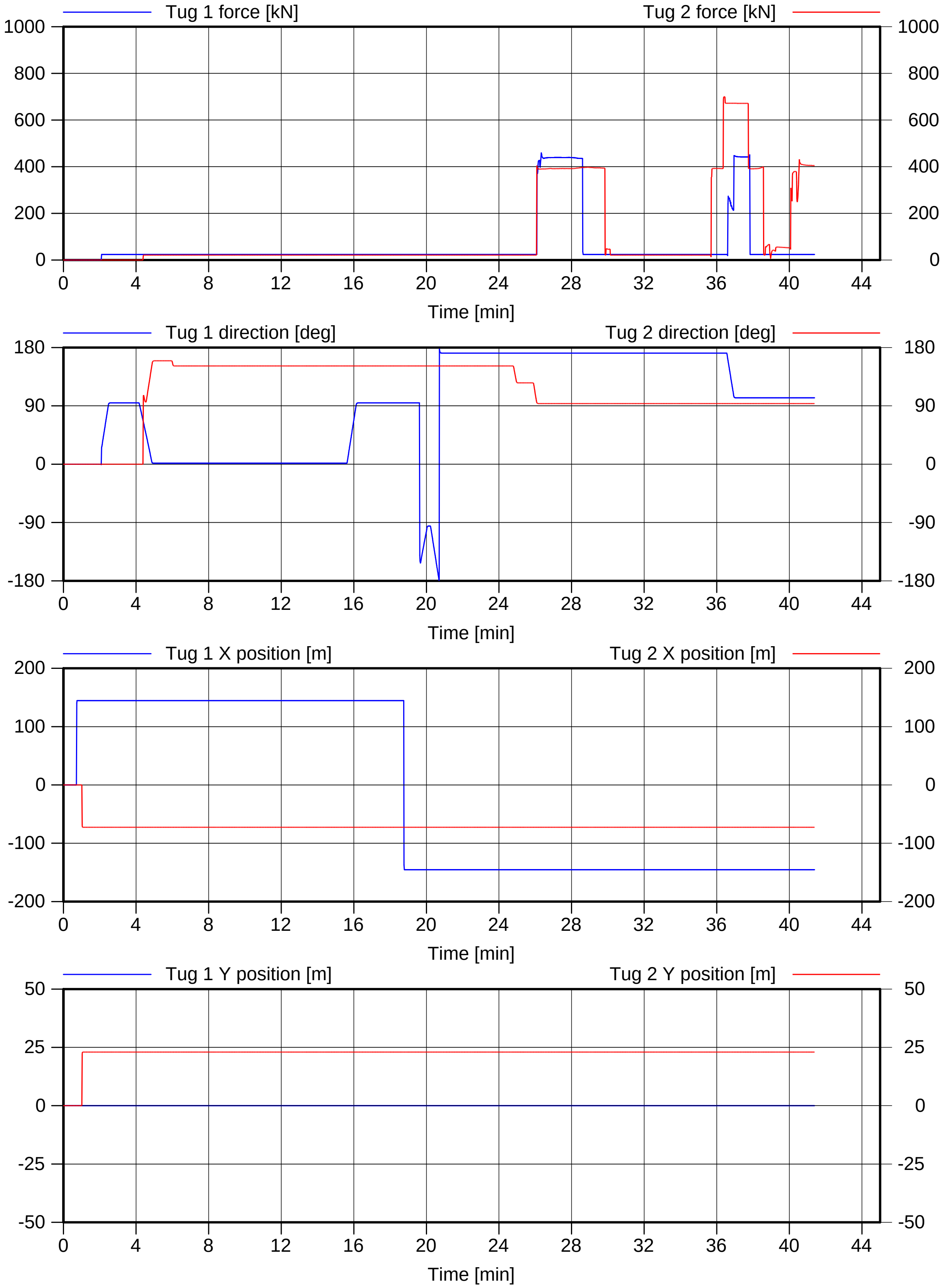
Run: 28	Malta
Arrival	Wind 12m/s from S
MARIN's Nautical Centre MSCN	Fig. 17.f



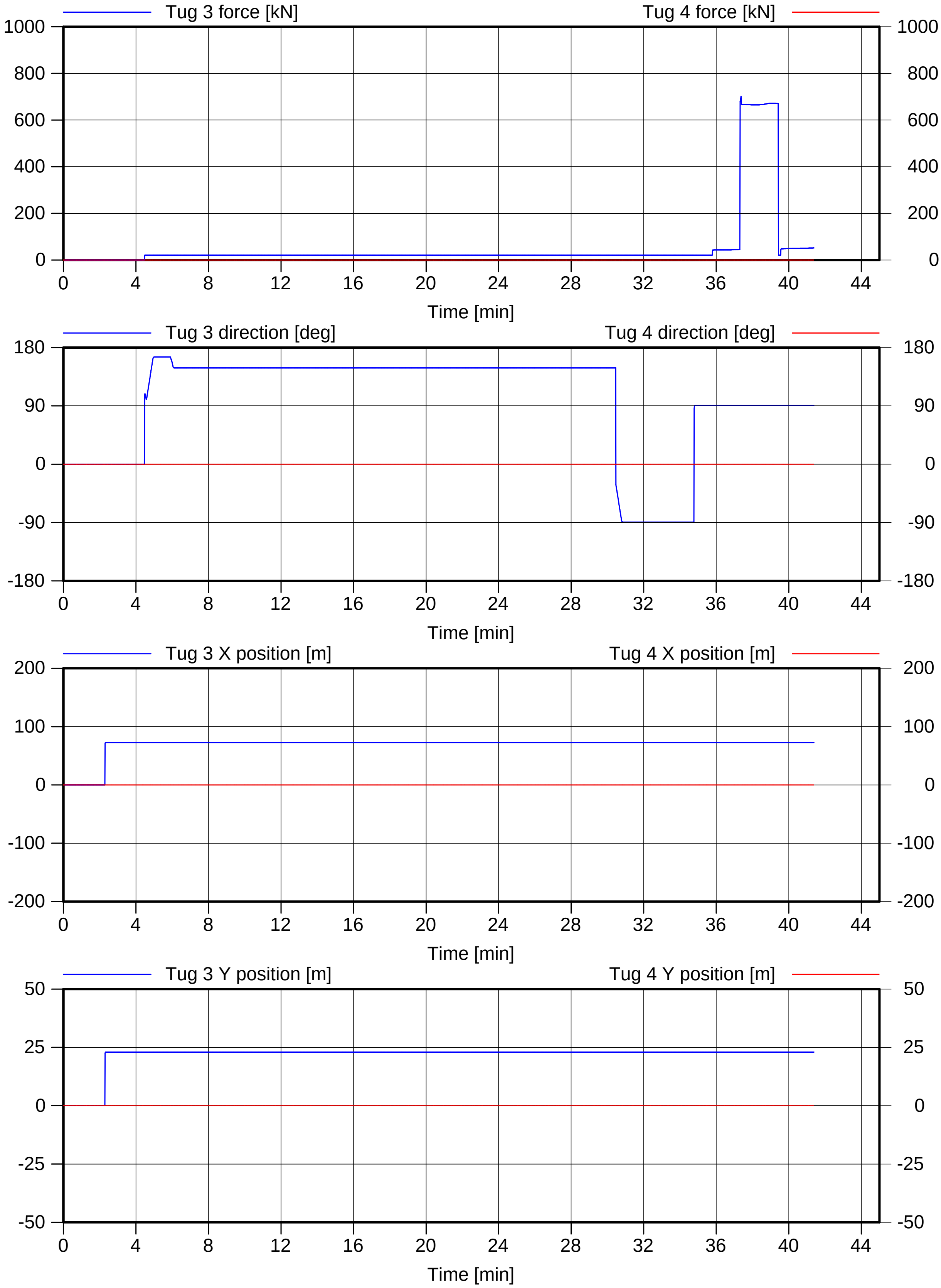
Run: 29	Malta
Arrival	Wind 12m/s from W
MARIN's Nautical Centre MSCN	Fig. 18.a



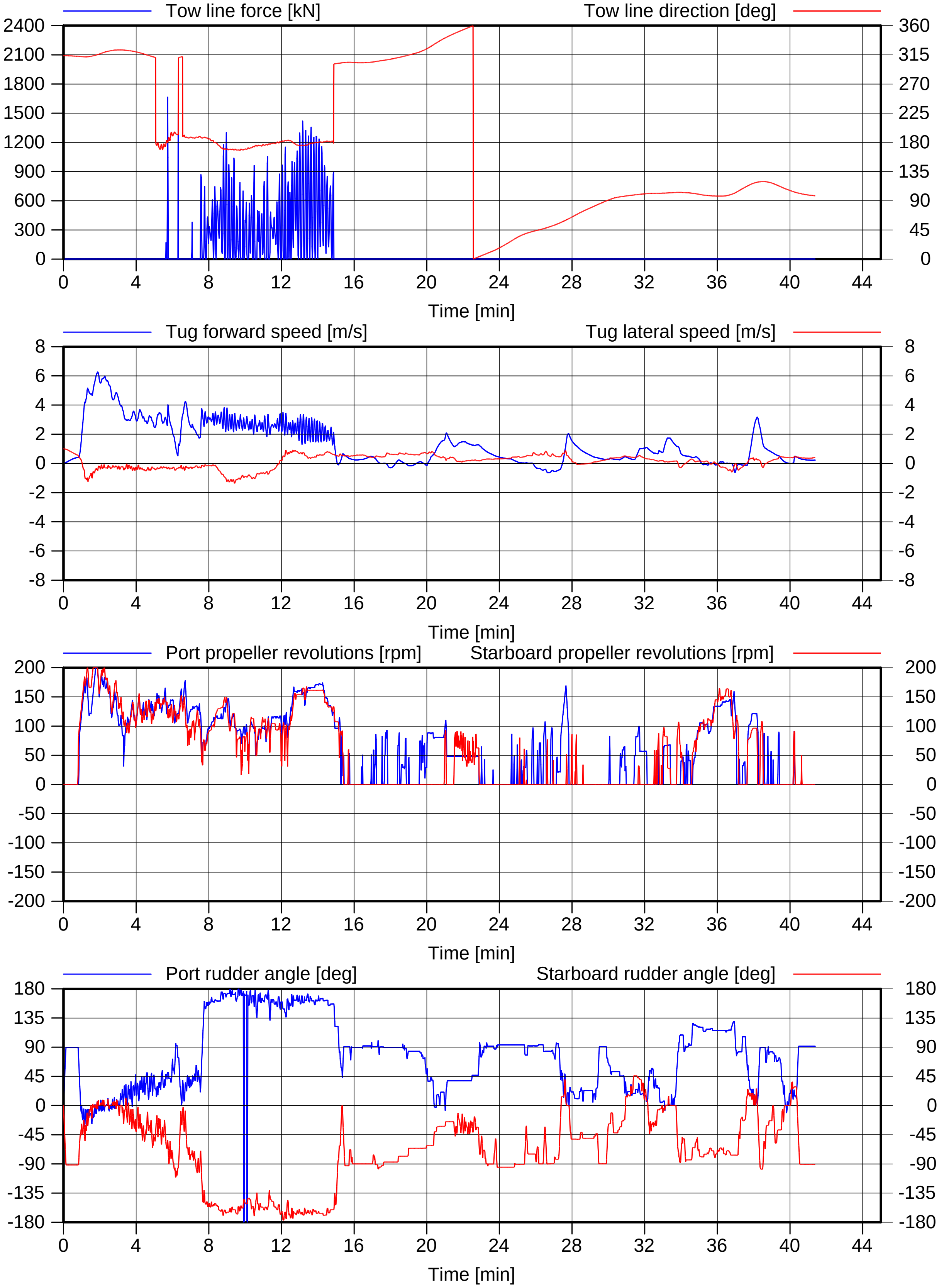
Run: 29	Malta
Arrival	Wind 12m/s from W
MARIN's Nautical Centre MSCN	Fig. 18.b



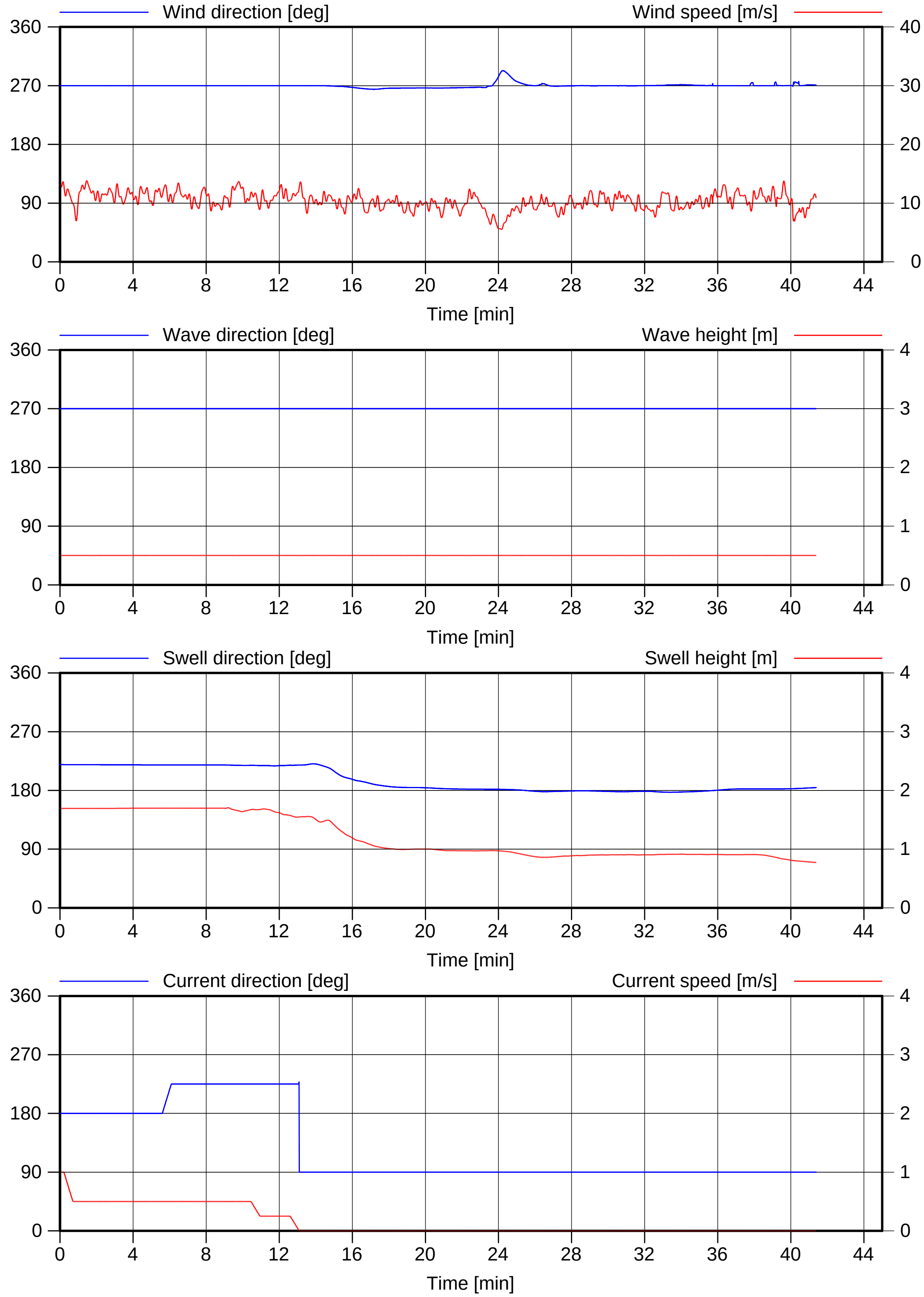
Run: 29	Malta
Arrival	Wind 12m/s from W
MARIN's Nautical Centre MSCN	Fig. 18.c



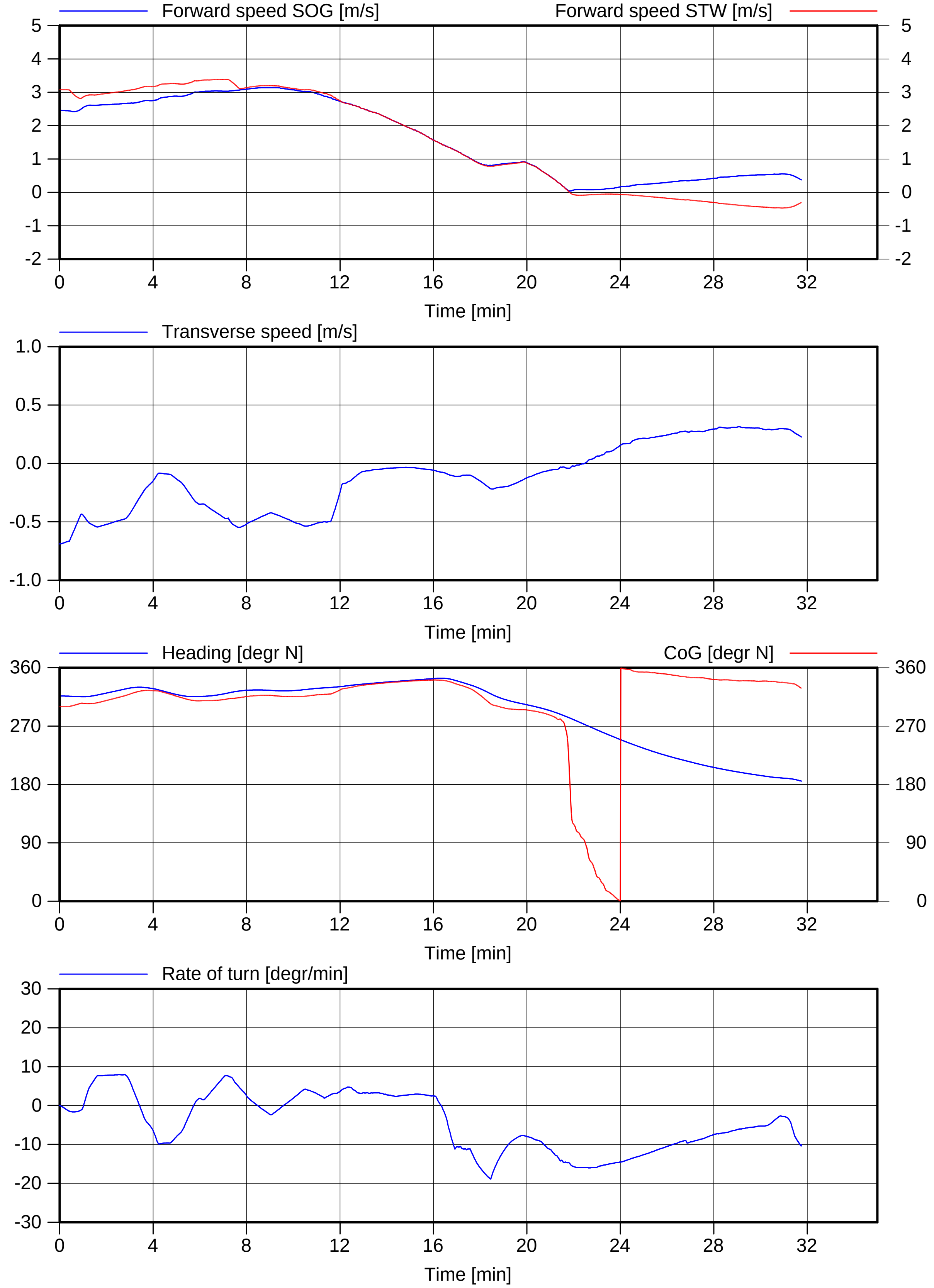
Run: 29	Malta
Arrival	Wind 12m/s from W
MARIN's Nautical Centre MSCN	Fig. 18.d



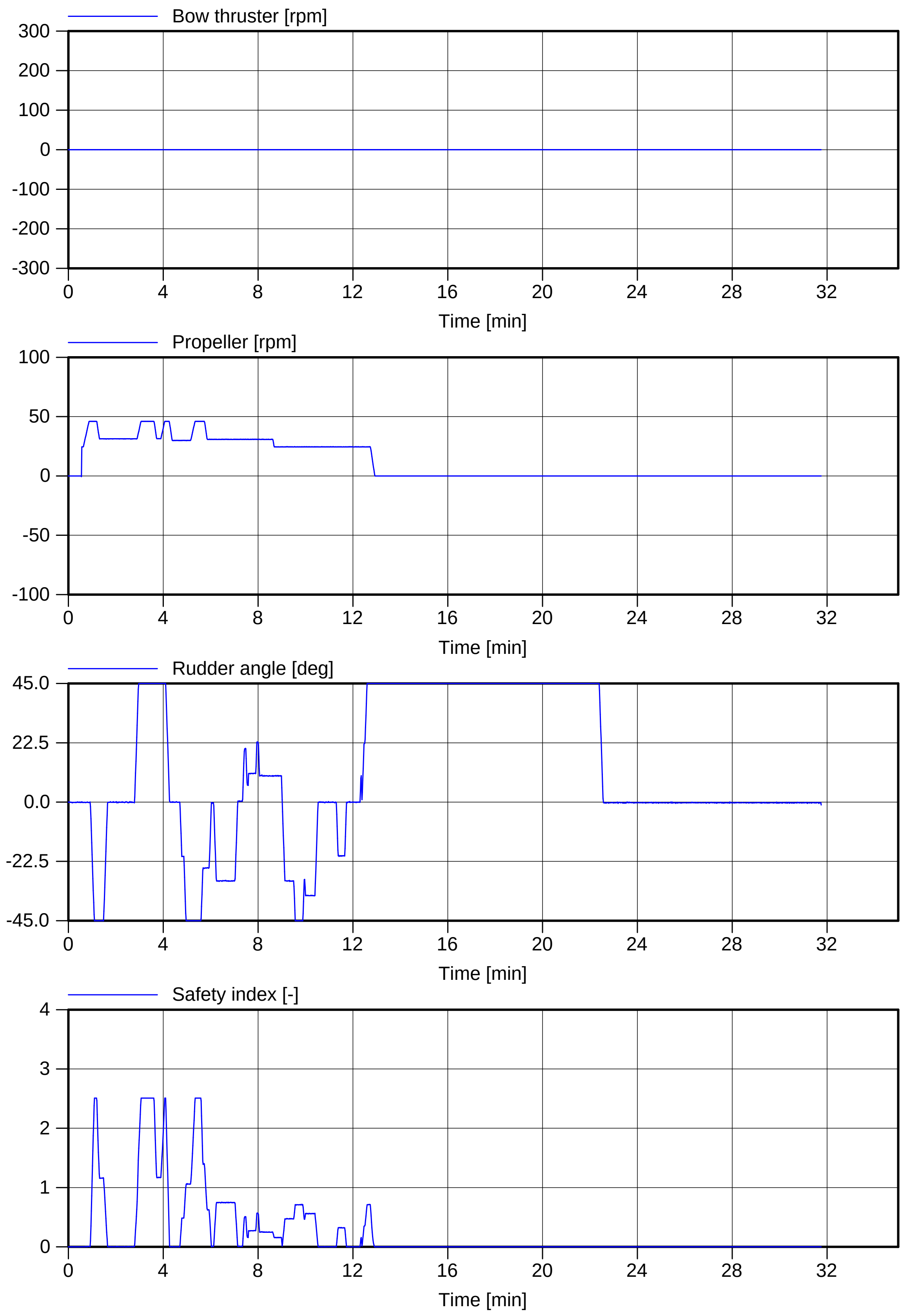
Run: 29	Malta
Arrival	Wind 12m/s from W
MARIN's Nautical Centre MSCN	Fig. 18.e



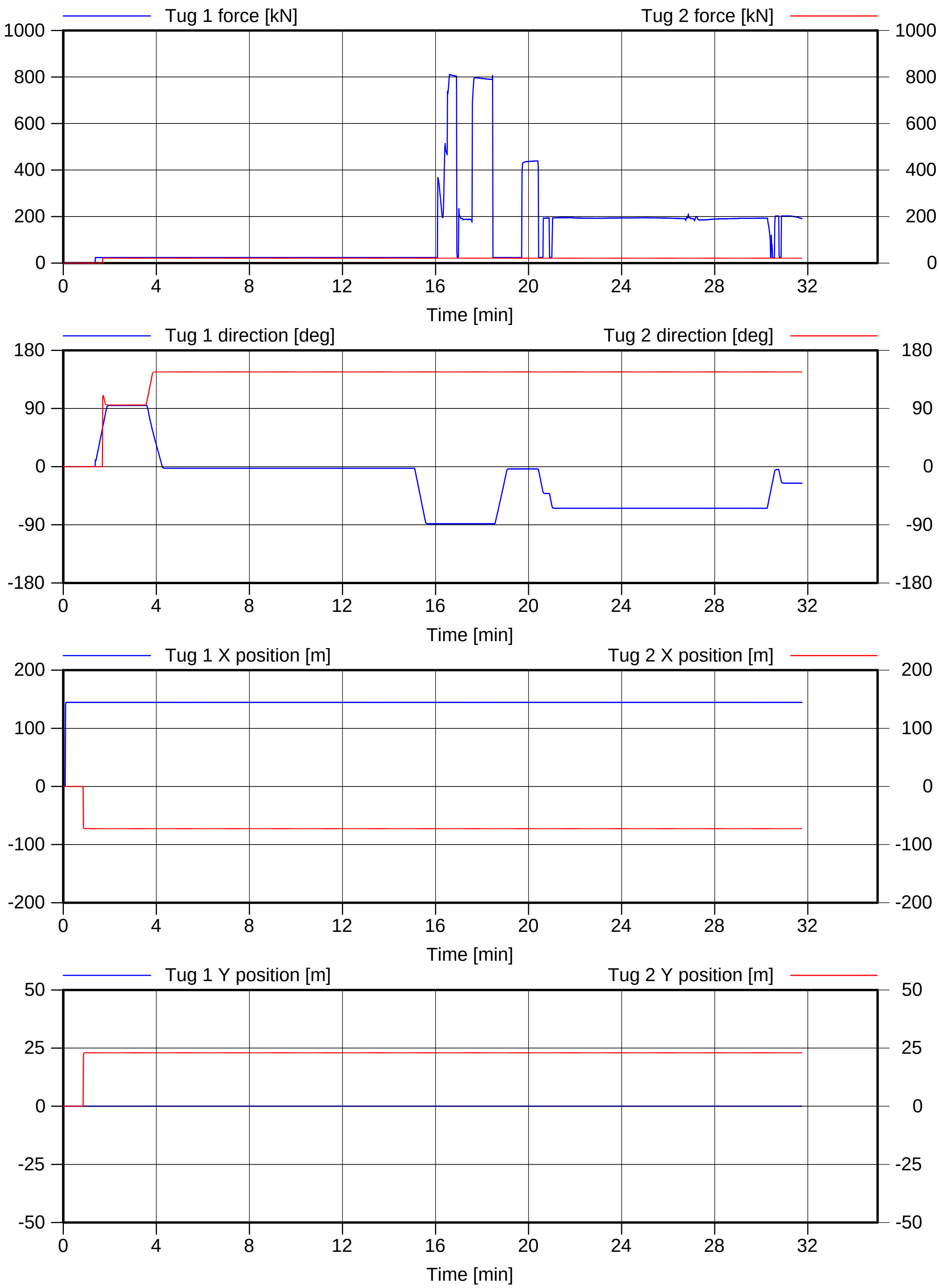
Run: 29	Malta
Arrival	Wind 12m/s from W
MARIN's Nautical Centre MSCN	Fig. 18.f



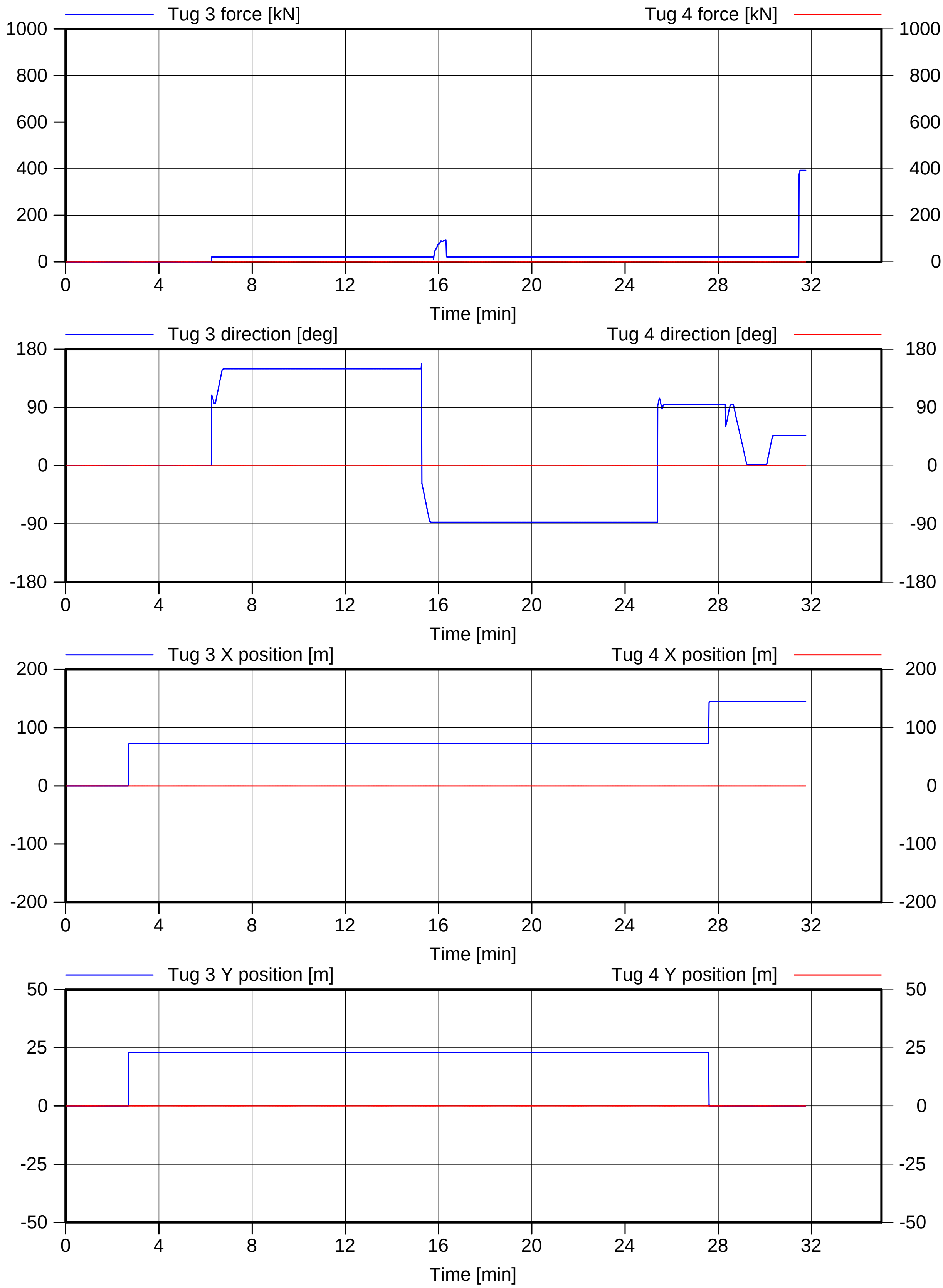
Run: 30	Malta
Arrival	Wind 12m/s from SE
MARIN's Nautical Centre MSCN	Fig. 19.a



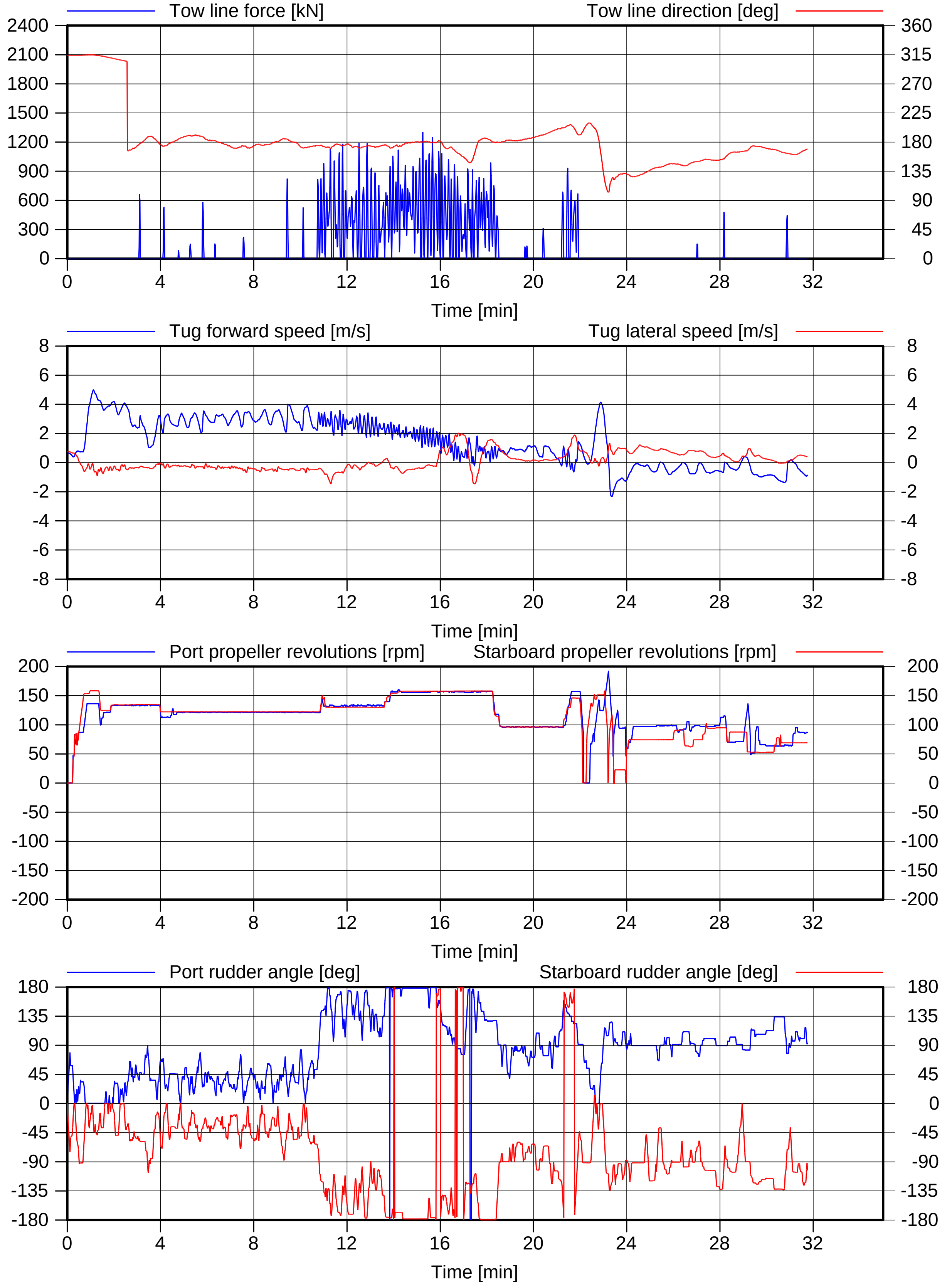
Run: 30	Malta
Arrival	Wind 12m/s from SE
MARIN's Nautical Centre MSCN	Fig. 19.b



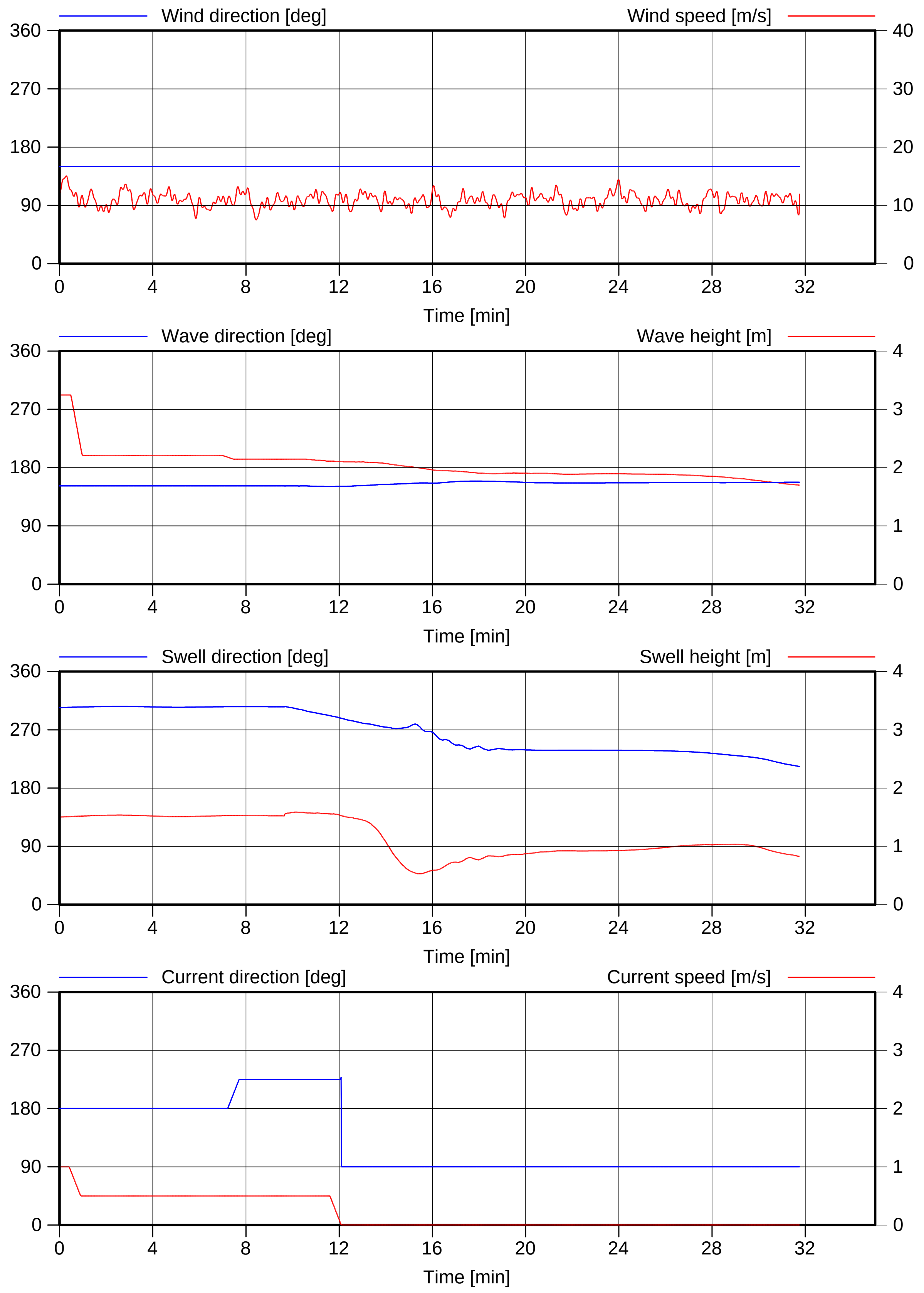
Run: 30	Malta
Arrival	Wind 12m/s from SE
MARIN's Nautical Centre MSCN	Fig. 19.c



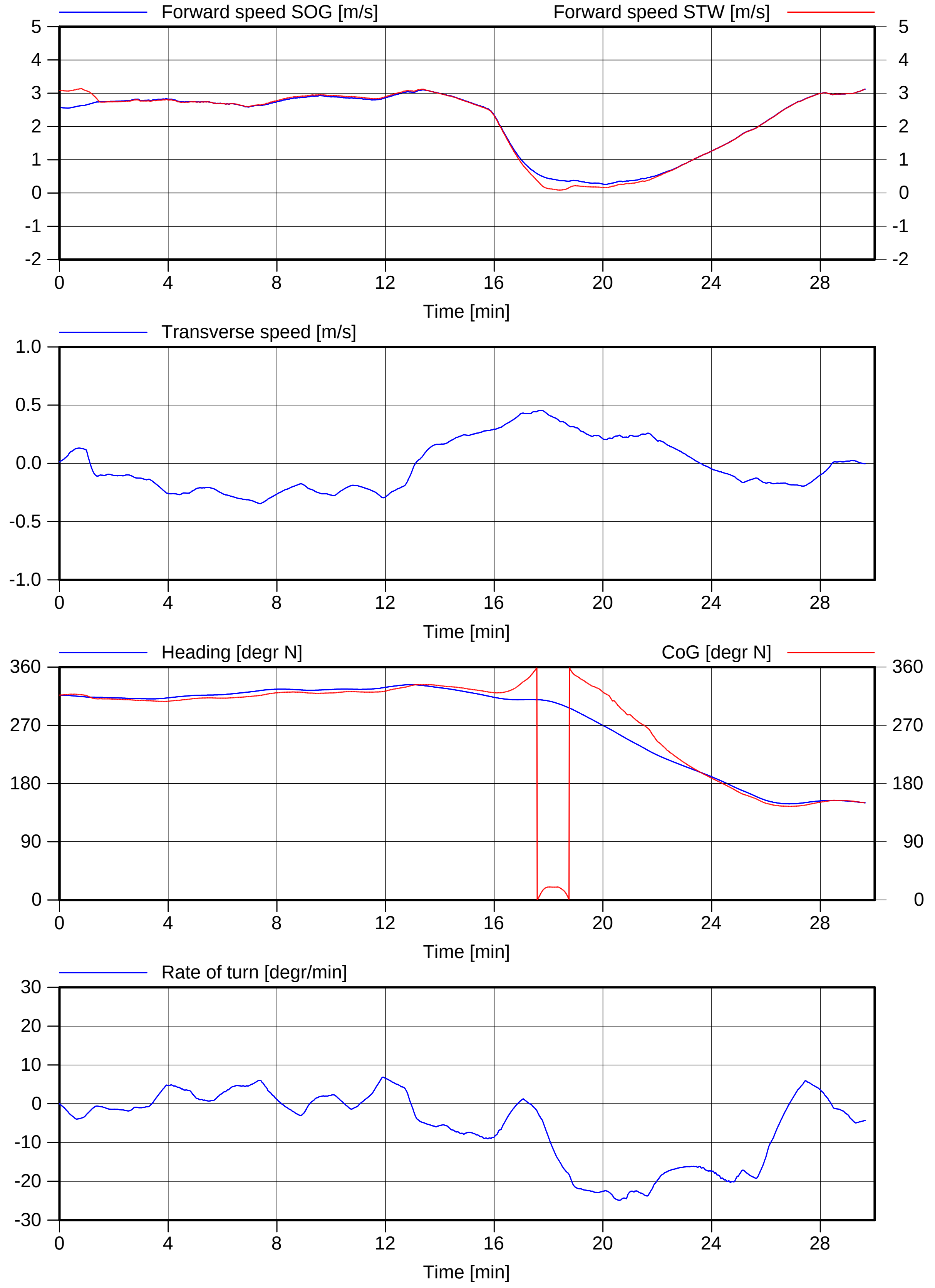
Run: 30	Malta
Arrival	Wind 12m/s from SE
MARIN's Nautical Centre MSCN	Fig. 19.d



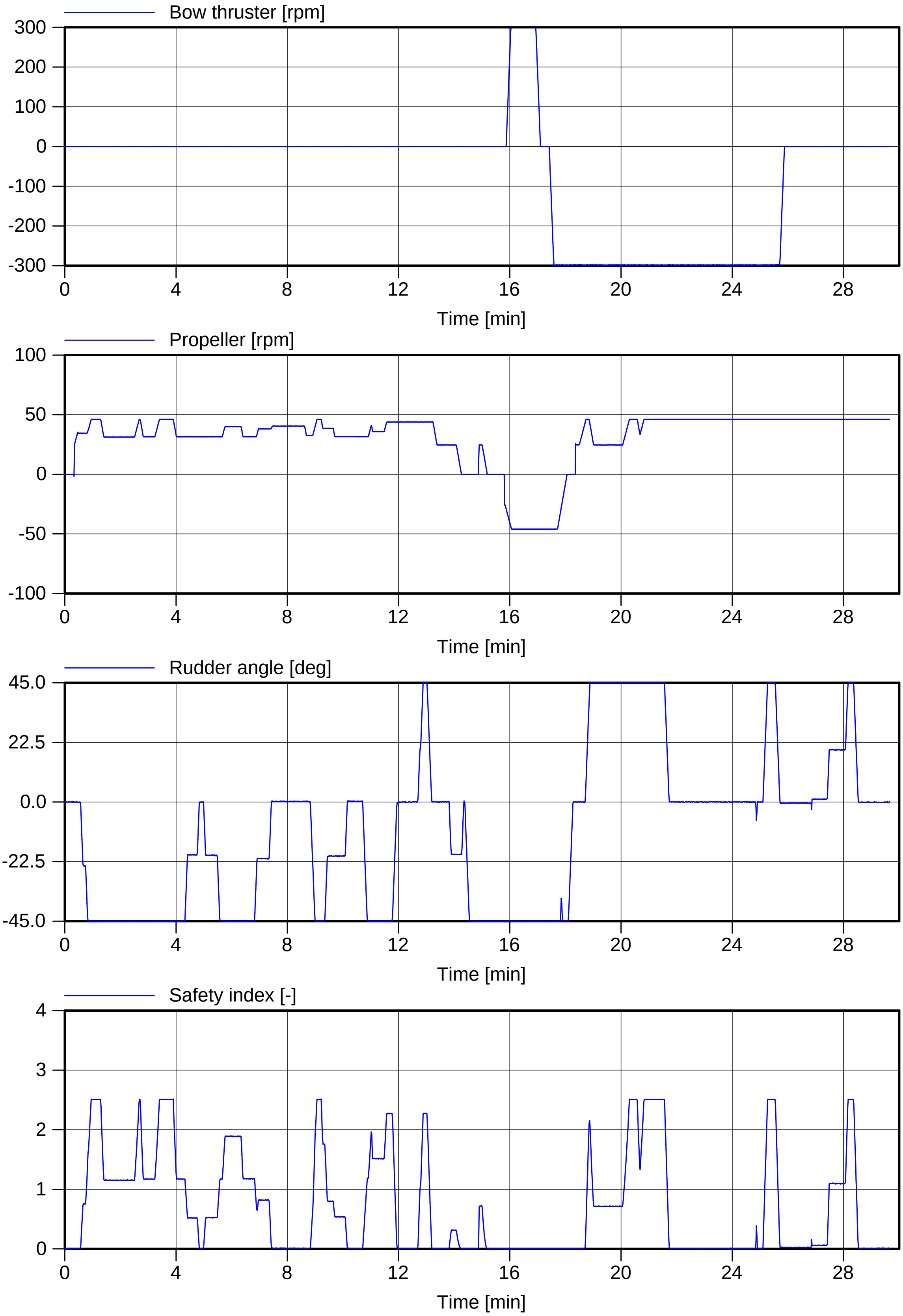
Run: 30	Malta
Arrival	Wind 12m/s from SE
MARIN's Nautical Centre MSCN	Fig. 19.e



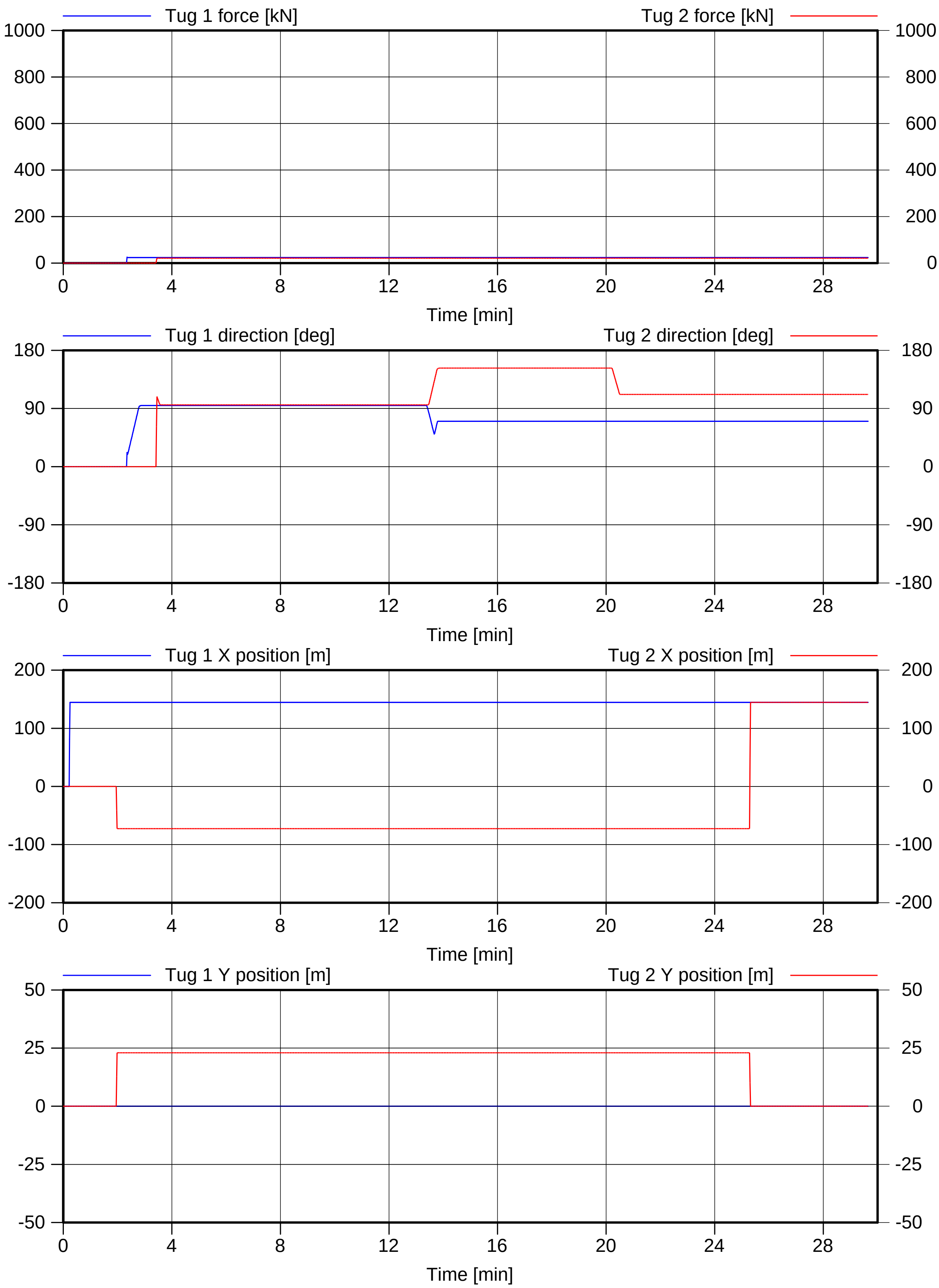
Run: 30	Malta
Arrival	Wind 12m/s from SE
MARIN's Nautical Centre MSCN	Fig. 19.f



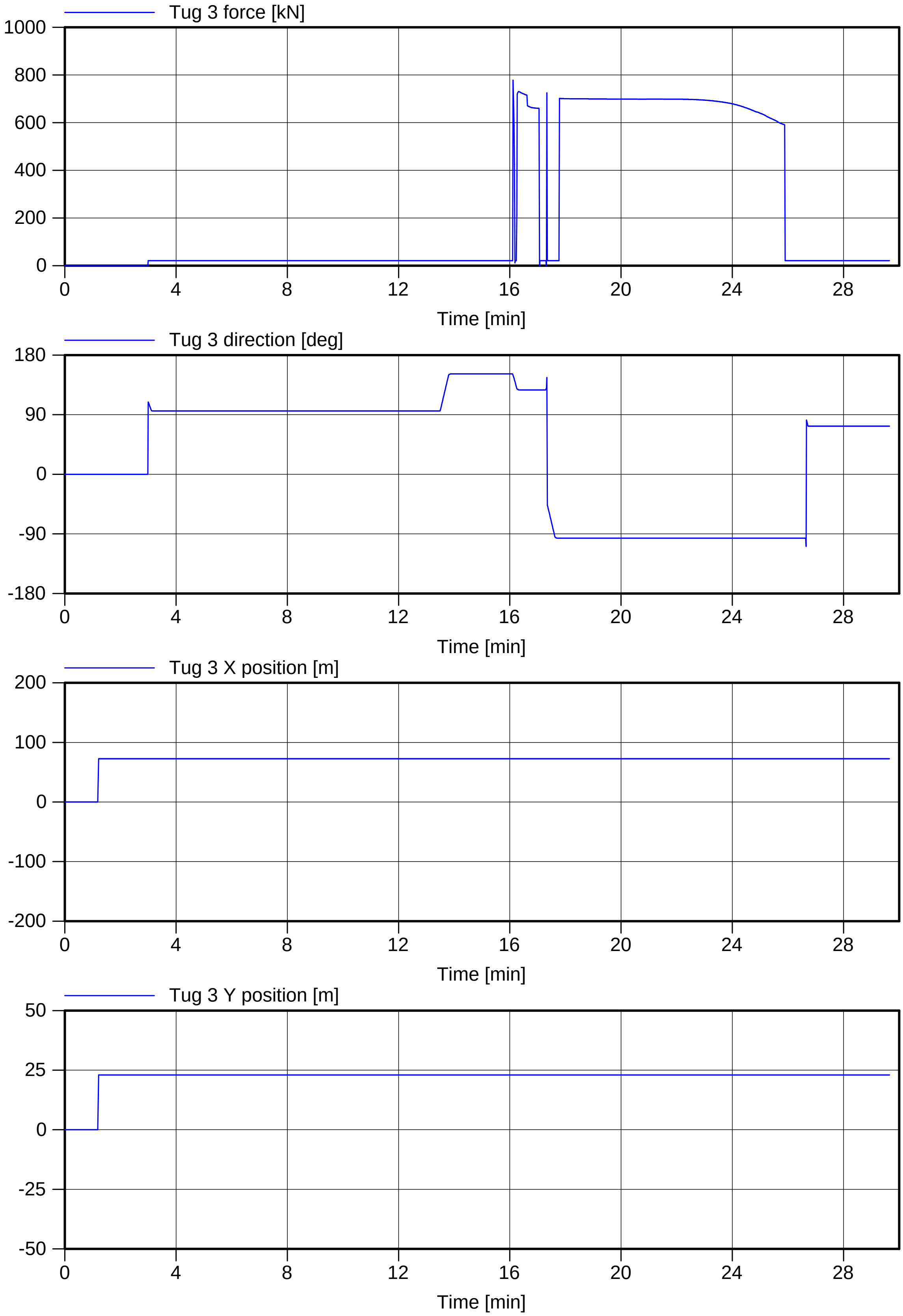
Run: 31	Malta
Arrival	Wind 12m/s from S
MARIN's Nautical Centre MSCN	Fig. 20.a



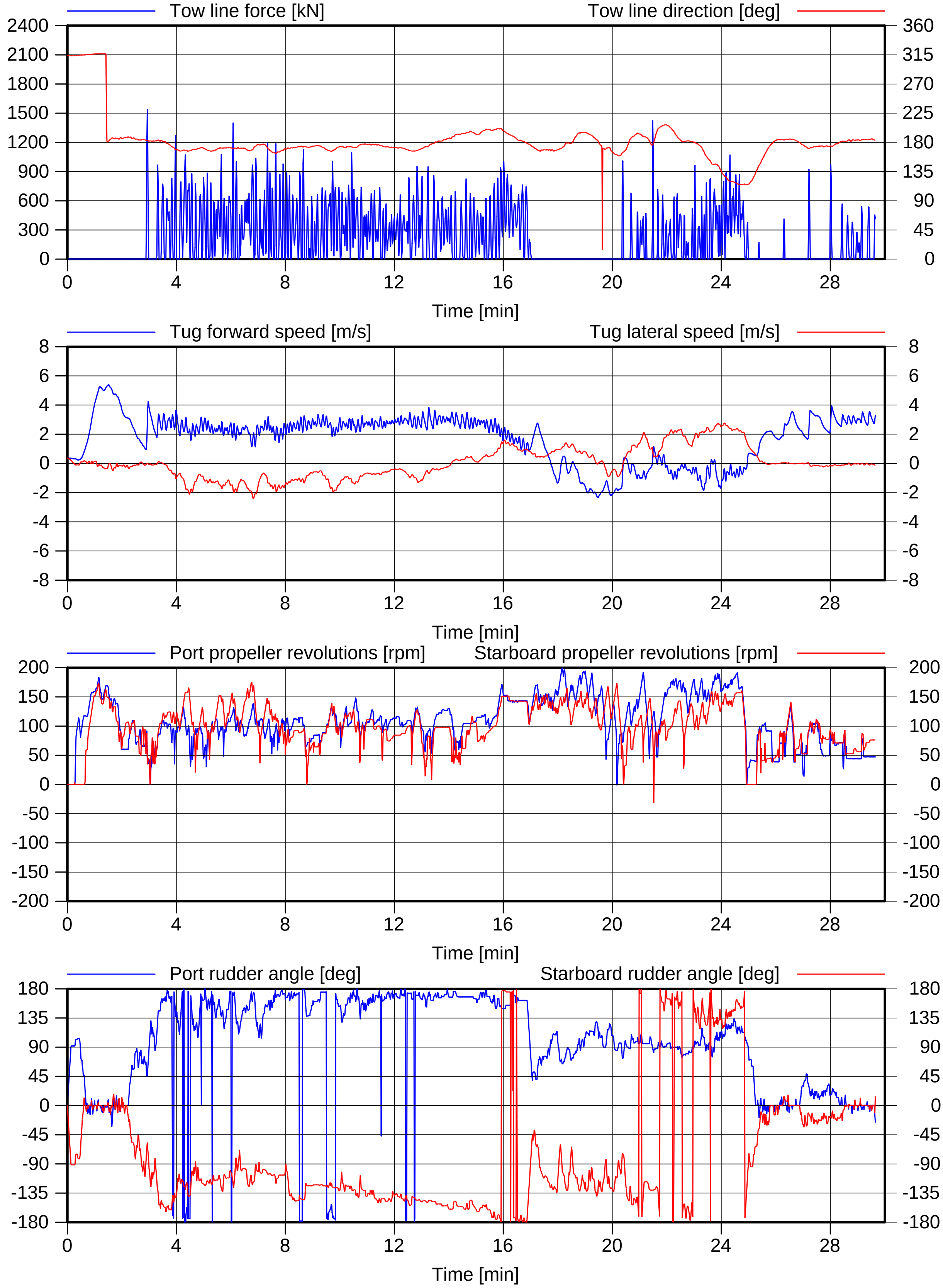
Run: 31	Malta
Arrival	Wind 12m/s from S
MARIN's Nautical Centre MSCN	Fig. 20.b



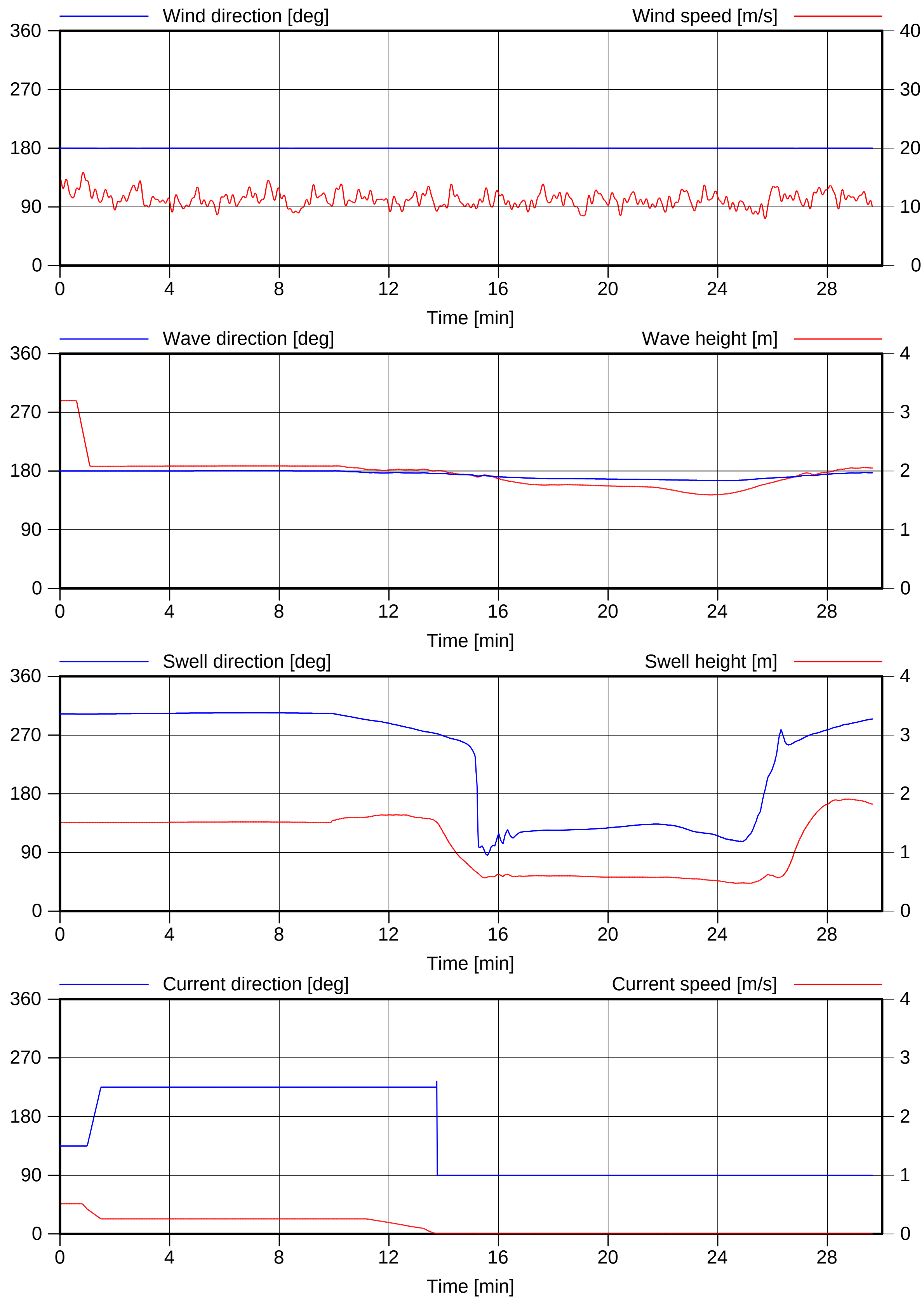
Run: 31	Malta
Arrival	Wind 12m/s from S
MARIN's Nautical Centre MSCN	Fig. 20.c



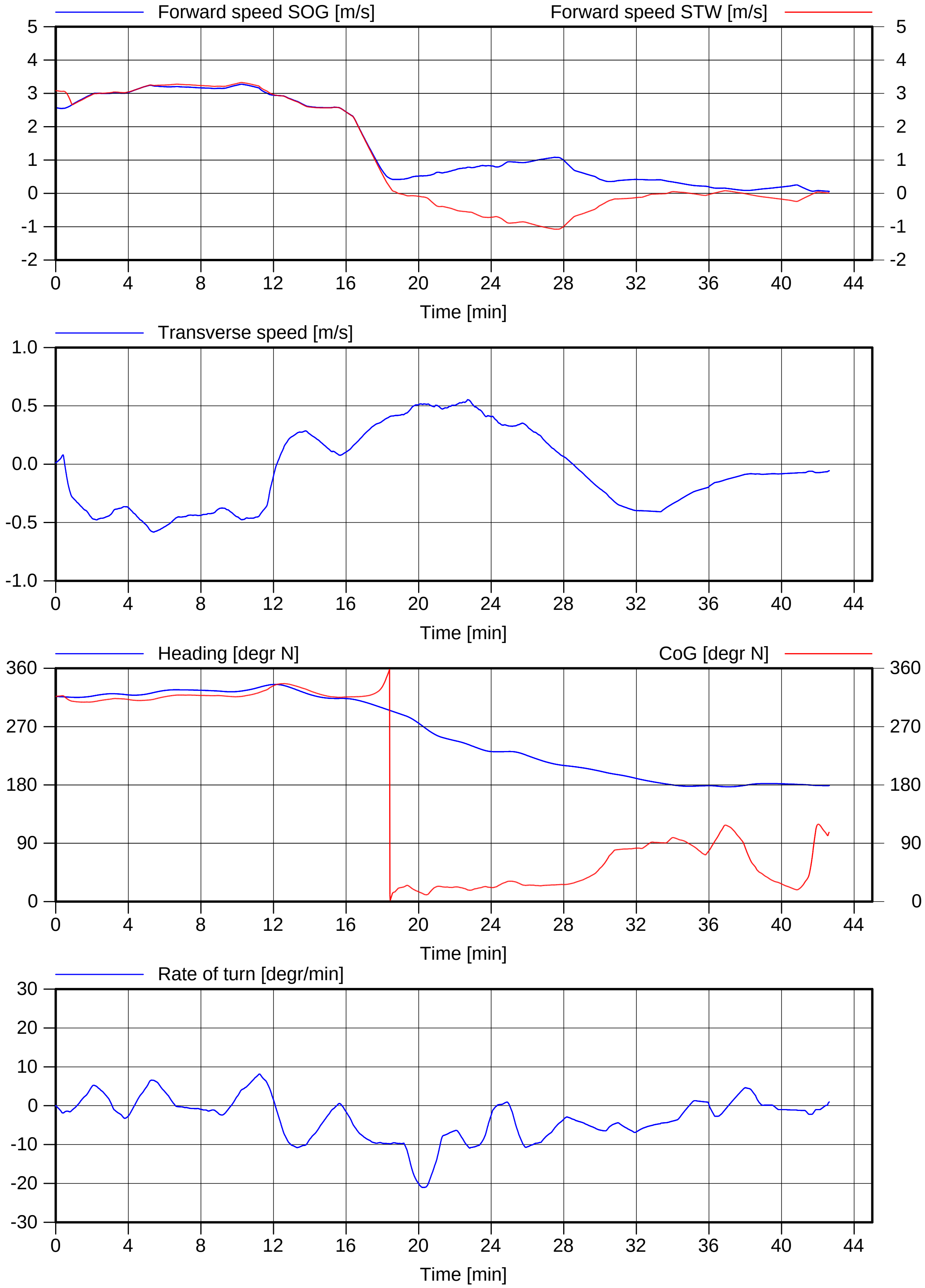
Run: 31	Malta
Arrival	Wind 12m/s from S
MARIN's Nautical Centre MSCN	Fig. 20.d



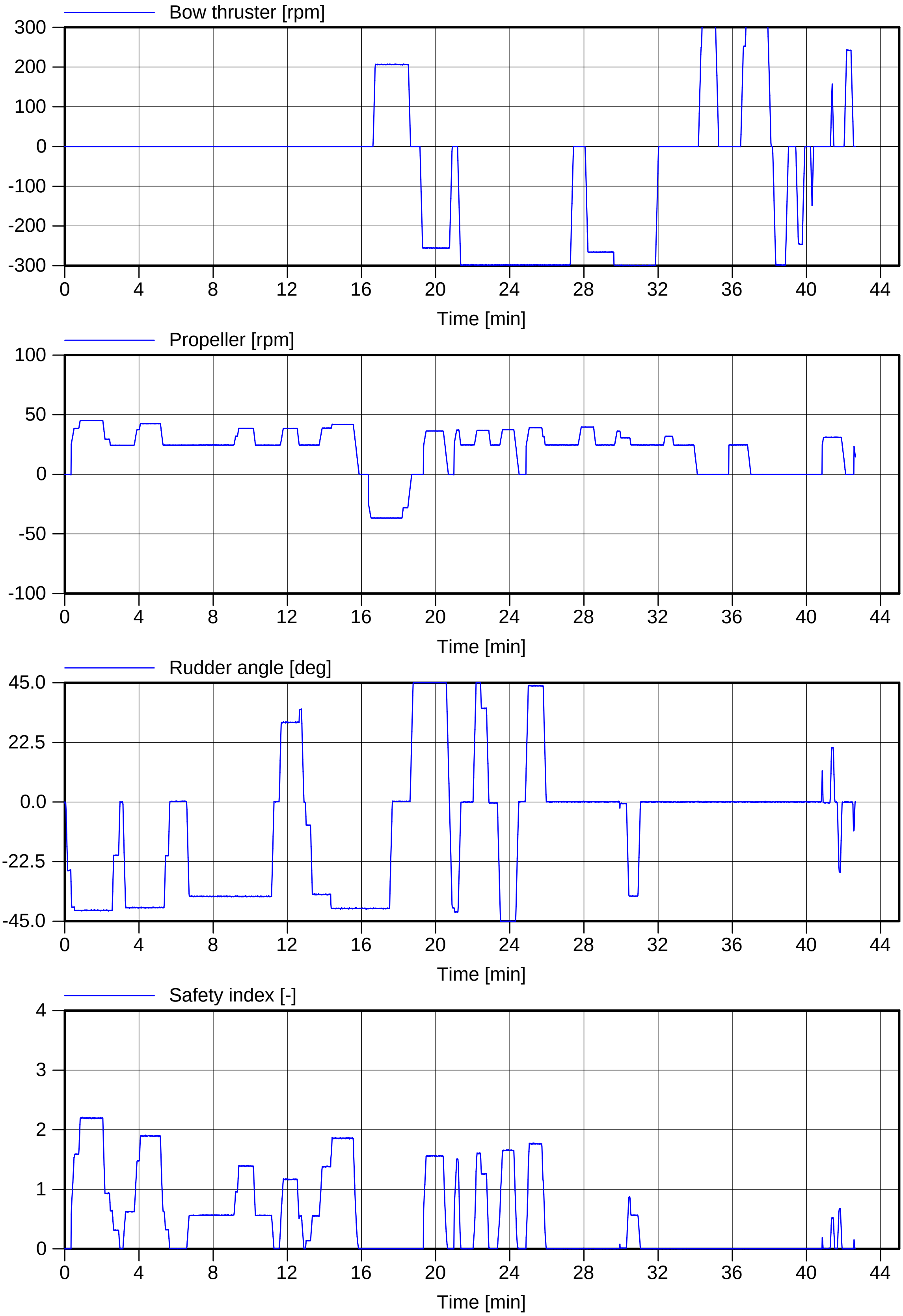
Run: 31	Malta
Arrival	Wind 12m/s from S
MARIN's Nautical Centre MSCN	Fig. 20.e



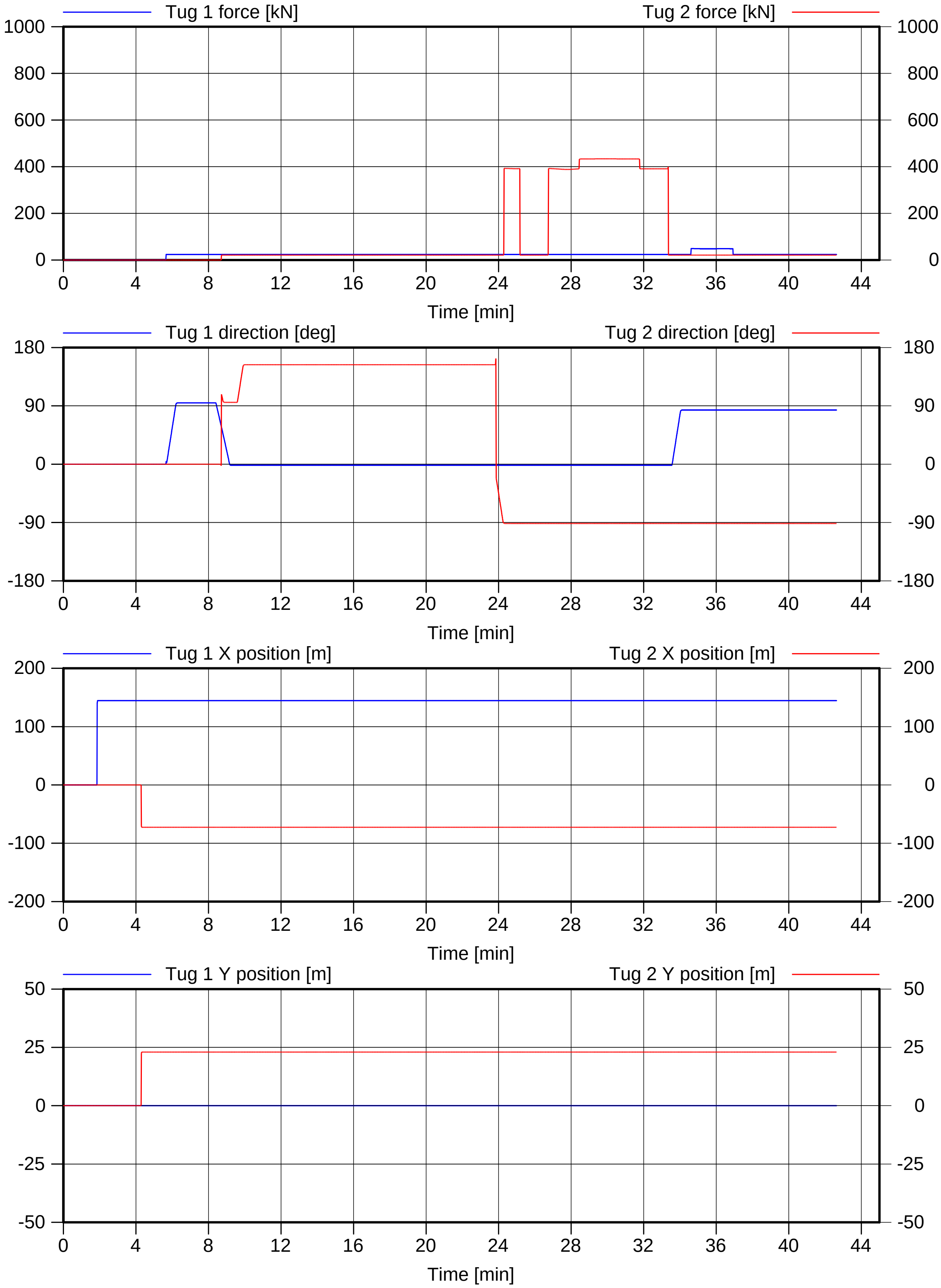
Run: 31	Malta
Arrival	Wind 12m/s from S
MARIN's Nautical Centre MSCN	Fig. 20.f



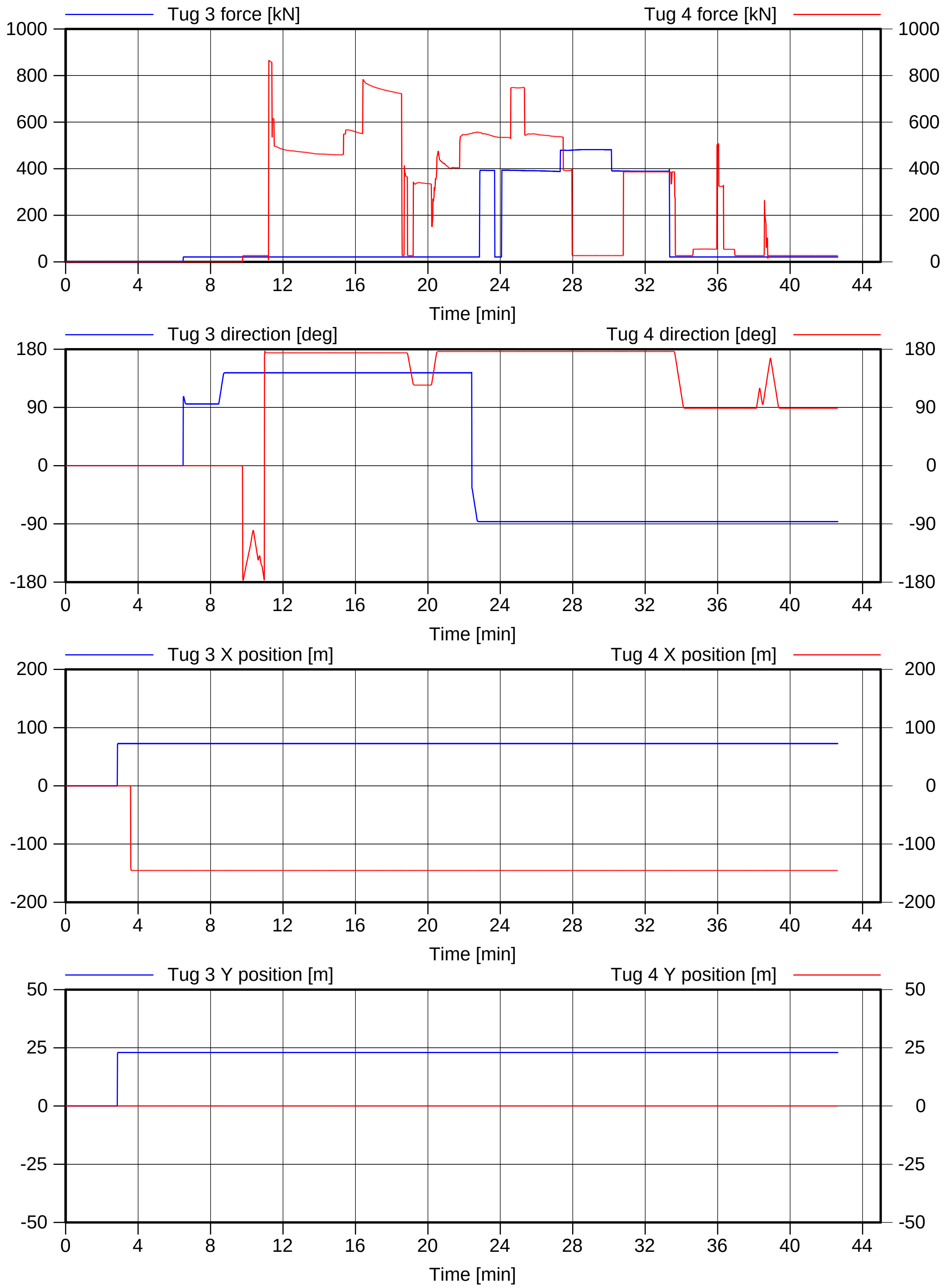
Run: 32	Malta
Arrival	Wind 14m/s from S
MARIN's Nautical Centre MSCN	Fig. 21.a



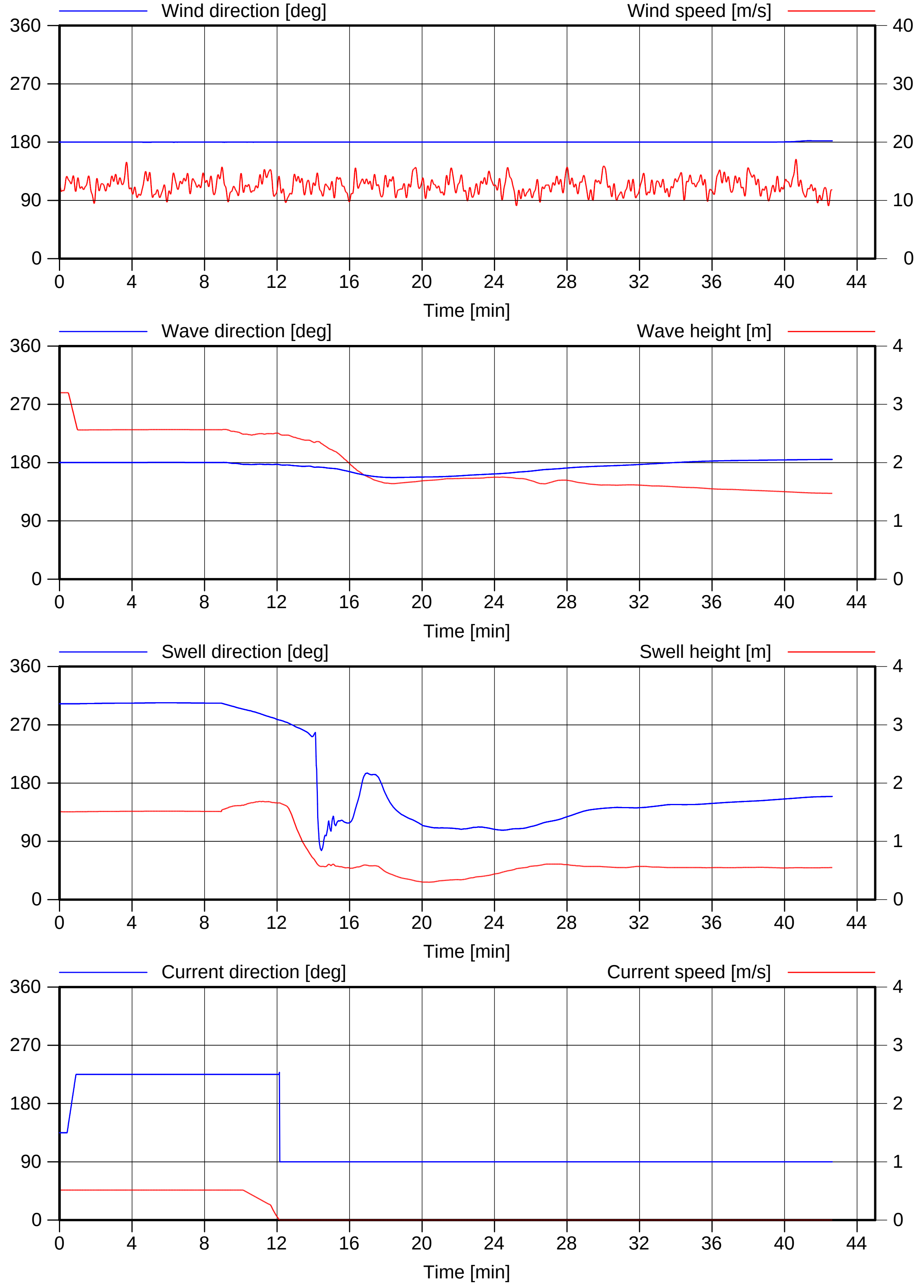
Run: 32	Malta
Arrival	Wind 14m/s from S
MARIN's Nautical Centre MSCN	Fig. 21.b



Run: 32	Malta
Arrival	Wind 14m/s from S
MARIN's Nautical Centre MSCN	Fig. 21.c



Run: 32	Malta
Arrival	Wind 14m/s from S
MARIN's Nautical Centre MSCN	Fig. 21.d



Run: 32	Malta
Arrival	Wind 14m/s from S
MARIN’s Nautical Centre MSCN	Fig. 21.f