Curtin University

Centre for Marine Science and Technology

Ship Motion Measurements for Ship Under-Keel Clearance in the Port of Fremantle

Prepared for:

Fremantle Ports

FREMANTLE PORTS

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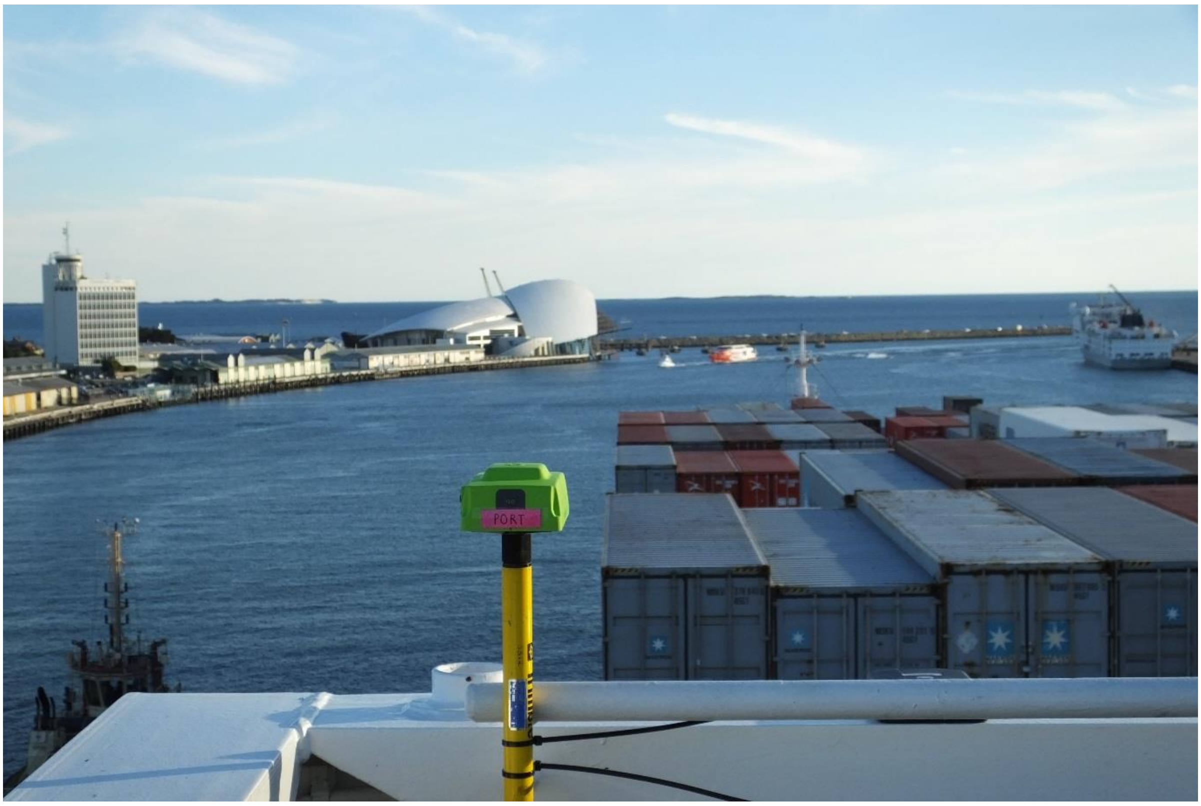
SUMMARY

This report presents some results from a series of recent full-scale trials on measuring dynamic sinkage, trim and heel of 16 container ship transits entering and leaving the Port of Fremantle via its Deep Water Channel, Entrance Channel and Inner Harbour. Measurements were carried out using high-accuracy GNSS receivers and a fixed reference station. Measured dynamic sinkage and elevations of the ship's keel relative to Chart Datum of 13 ship transits are shown. Three ship transits are excluded from this report due to their poor GNSS signals.

In future work, a theoretical method using slender-body shallow-water theory will be applied to predict the sinkage and trim of the transits, and the measured results will also be used for validating wave-induced motions software.



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1. DETAILS OF SHIP MOTION TRIALS

At the Port of Fremantle, full-scale trials were performed on 16 inbound and outbound container ships via its Deep Water Channel, Entrance Channel and Inner Harbour (see chart AUS112 and 113).

1.1. Ships and measurement dates

Measurements were made on 16 container ship transits in total, on the following dates:

- MSC ILONA, outbound, Sat 16th April 2016
- OOCL HOUSTON, outbound, Sat 16th April 2016
- SEAMAX STAMFORD, inbound, Sun 17th April 2016
- SEAMAX STAMFORD, outbound, Sun 17th April 2016
- CMA CGM CHOPIN, inbound, Mon 18th April 2016
- MOL EMISSARY, inbound, Mon 18th April 2016
- CMA CGM CHOPIN, outbound, Mon 18th April 2016
- MOL EMISSARY, outbound, Tues 19th April 2016
- SAFMARINE MAKUTU, inbound, Wed 20th April 2016
- MOL PARAMOUNT, inbound, Thurs 21st April 2016
- SAFMARINE MAKUTU, outbound, Thurs 21st April 2016
- CMA CGM LAMARTINE, outbound, Fri 22nd April 2016
- MOL PARAMOUNT, outbound, Fri 22nd April 2016
- OOCL BRISBANE, inbound, Sun 24th April 2016
- CMA CGM WAGNER, inbound, Mon 25th April 2016
- OOCL BRISBANE, outbound (partial pilotage), Mon 25th April 2016

Ship dimensions and comparative transit conditions for all the ships are shown in Appendix A.

1.2. Ship motion measurement equipment

Ship motions were measured using JAVAD Triumph-1 and Triumph-2 GNSS receivers. Four receivers were used for each set of measurements, with one in each of the following locations:

- Base station fixed to pilot jetty
- Roving receiver fixed to ship bow
- Roving receiver fixed to port bridge wing
- Roving receiver fixed to starboard bridge wing

An example setup is shown in Figure 1.

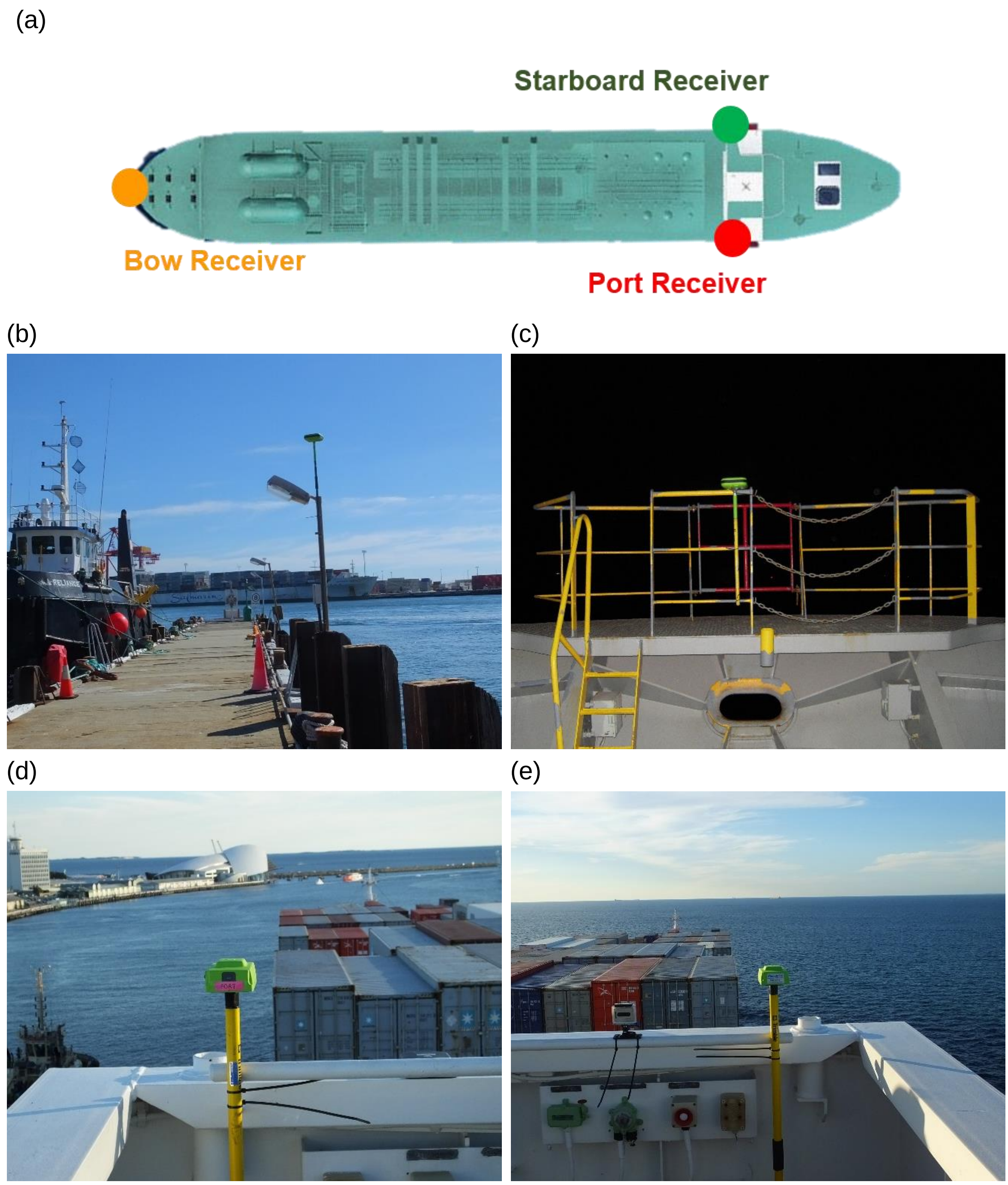


Figure 1. GNSS receivers setup. (a) Plan view of ship receivers. (b) Base station on pilot jetty in the CMA CGM LAMARTINE (outbound) transit. (c) Bow receiver in the MOL PARAMOUNT (outbound) transit. (d) Port receiver on bridge wing in the SAFMARINE MAKUTU (outbound) transit. (e) Starboard receiver on bridge wing in the SAFMARINE MAKUTU (outbound) transit.

With reference to the (b) in Figure 1, the base station was placed at the same point (32° 2.52236’ S, 115° 45.19799’ E) on pilot jetty for all the transits, as shown in Figure 2.

Figure 2. Base station location on pilot jetty

1.3. Description of the procedure

The procedure for inbound transits is:

- CMST researchers board vessel with pilot
- Set up GNSS receivers on bow and both port and starboard bridge wings (symmetric positions)
- Data recording throughout pilotage
- Remove equipment and disembark with pilot

The procedure for outbound transits is the reverse of the above. Data recording covers a period of time before departure or after arrival to take a stationary reading at the berth. In our trials, data recording was commenced prior to leaving the berth for the outbound transits and continued until after all mooring work had been completed for the inbound transits. The at-berth measurements are then used as a reference value for comparing the vertical height measurements while under way.

2. ENVIRONMENTAL DATA

Some of the wave data from the Cottesloe wave buoy (31° 58.74333' S, 115° 41.39833' E) near Green No.1 Buoy (G1) in the Deep Water Channel have been provided from collaboration with the Coastal infrastructure team from WA Department of Transport. The full measured wave data will be used to study wave-induced motions in the channel, in future work. This information is held in the onboard memory and hence the whole data may be provided when WA DoT recovers the wave buoy for the next annual maintenance service. The wave data provided by WA DoT is presented in Appendix B, and the photos of the Cottesloe wave buoy that we took during the trials are shown in Figure 3.

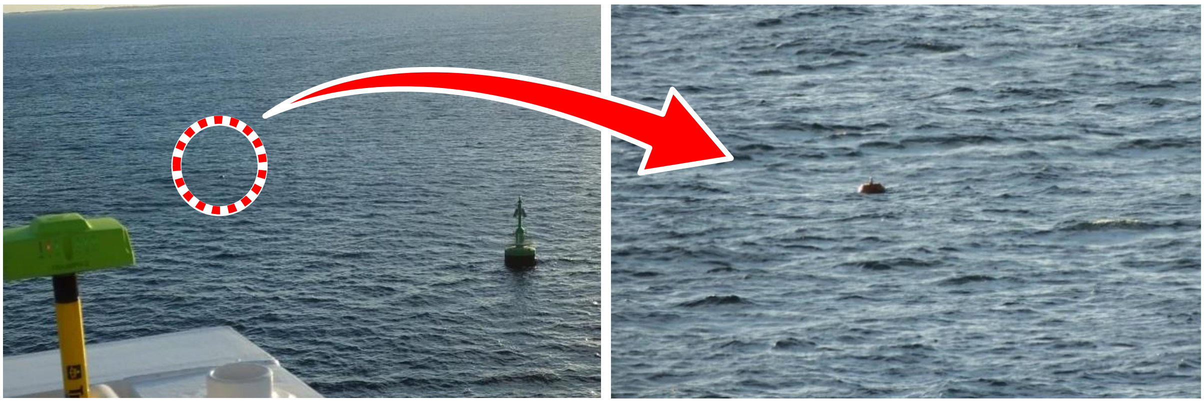


Figure 3. The Cottesloe wave buoy and its location.

Local tide data that is raw sea surface elevations as measured in the Inner Harbour (32° 3.258' S, 115° 44.3718' E) in the Port of Fremantle has also been provided by Fremantle Ports and then applied to calculate dynamic sinkage of the ships. The tidal data covers the period of our measurements is described in Appendix C.

Regarding wind conditions, our observations on wind speeds and directions were made and recorded during each ship transit, shown in Appendix C. The full measured wind data can be obtained from the Bureau of Meteorology if required.

3. BATHYMETRIC DATA

To give the keel heights relative to the seabed, it would be helpful to have more accurate bathymetric data than given water depths on the nautical charts (AUS112 and 113). Detailed survey data for the Deep Water Channel, Entrance Channel and Inner Harbour has been provided by Fremantle Ports. The data is originally from Fremantle Ports' annual Hydrographic Survey carried out in September and October 2015 and composed of 144,150 survey points for the Entrance Channel and Inner Harbour, and 90,566 survey points for the Deep Water Channel. Figure 4 shows the survey points in the channels together with an example of the ship tracks (SEAMAX STAMFORD, inbound).

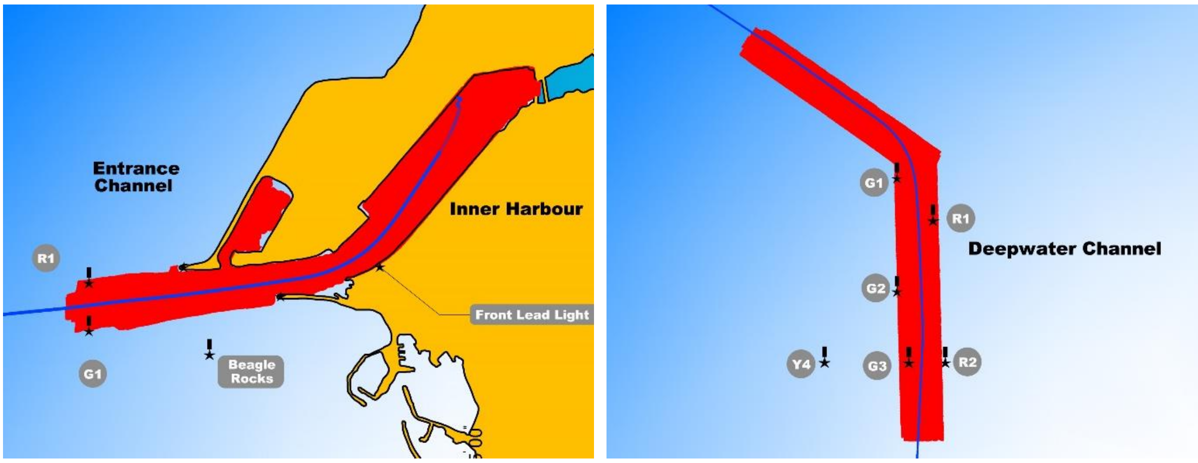


Figure 4. Bathymetric data from Fremantle Ports' annual Hydrographic Survey.

We wish to take water depths along the track from the bathymetric data to more accurately compare the ship's keel heights and the seabed. Z-values of the survey points that are the closest points to the track on the plane have been extracted, using Matlab, Excel and AutoCAD. A comparison between the bathymetry based on AUS112 and that extracted is shown in Figure 5. A flat seabed line is based on the charted depth on AUS112, and a fluctuating seabed line is the actual survey line provided by Fremantle Ports.

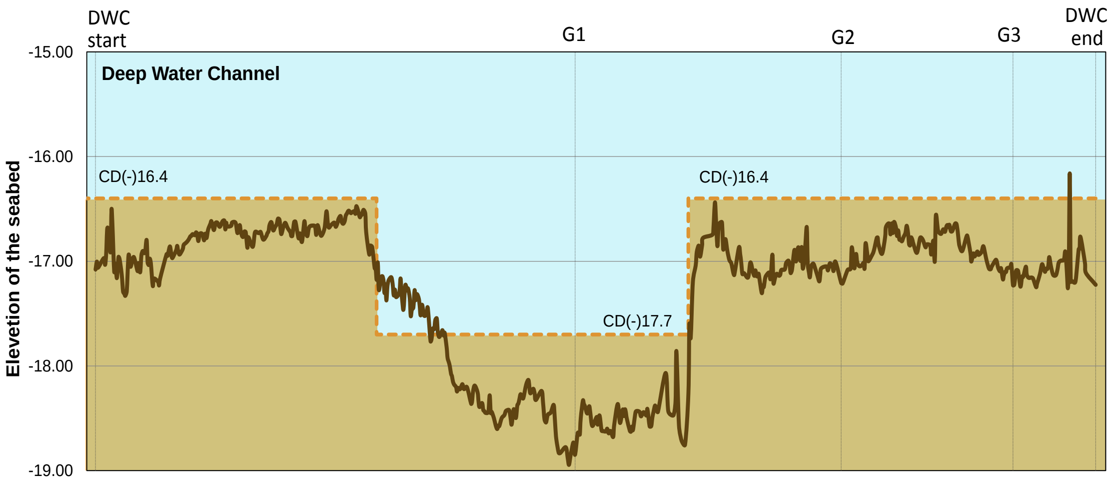


Figure 5. A comparison of the seabed lines based on the chart and the survey.

4. DATA PROCESSING

All data was post-processed using the Trimble Business Centre software, and the raw GNSS results for each receiver combined to give the sinkage at the forward, aft and transverse extremities of the keel. Sinkage is here defined as being positive downward. Figure 6 shows height components for calculating sinkage from GNSS height measurements.

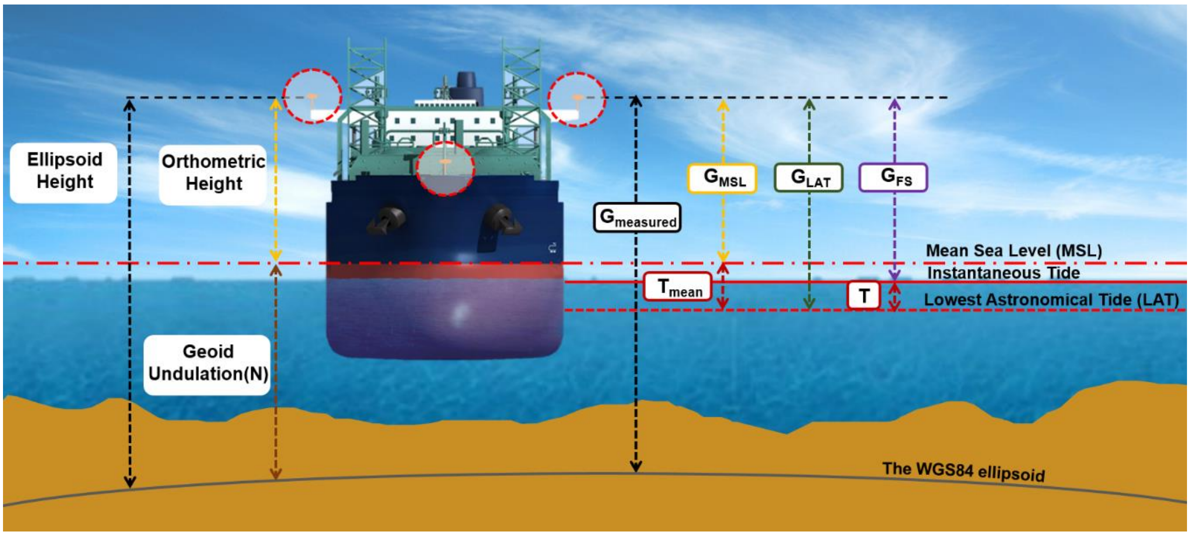


Figure 6. Components for calculating sinkage from GNSS height measurements.

Note that gaps in the data of some transits are due to GNSS fixes being of insufficient quality and being rejected. Particularly, three ship transits including MSC ILONA (outbound), SEAMAX STAMFORD (outbound) and OOCL BRISBANE (outbound) have been excluded from this report due to their poor GNSS signals.

5. RESULTS

5.1. Measured ship tracks

The Port of Fremantle and its approach channels and buoys together with tracks of the seven inbound ships and the six outbound ships are illustrated in Appendix D. The channels are varying in depth from 14.7m to 17.7m based on the Chart Datum, which is approximately the level of LAT (Lowest Astronomical Tide). An additional depth of up to 1.3m can be considered by tides, i.e. HAT (Highest Astronomical Tide) and MSL (Mean Sea Level) in the Port of Fremantle are 1.3m and 0.7m respectively (see chart AUS112). For the outbound ships, the measurements were made from the berth until the ships passed the last buoy (Green No.1) at the curved section in the Deep Water Channel.

5.2. Individual measurement results

Measured sinkage, together with ship speed and channel bathymetry, are shown in Appendix E. Sinkage is given at the FP, AP, and port and starboard bilge corners.

Results are plotted against cumulative distance from the Front Lead Light (32° 3.22728' S, 115°

44.45048' E). Vertical lines are shown for South Mole (SM), North Mole (NM) and Green No.1 Buoy (G1) in the Entrance Channel. In the Deep Water Channel, vertical lines are shown at the starting point, Green No.1 Buoy (G1), Green No.2 Buoy (G2), Green No.3 Buoy (G3) and the end point.

For practical UKC management, the ship's vertical position should be plotted, relative to Chart Datum, so that the port may know the actual real-time clearance from the seabed. Appendix E also includes these vertical elevation changes. The minimum real-time clearance in each section of varying water depth has been captured.

Maximum sinkage results for the ships are shown in Table 1.

Table 1. Measured maximum sinkage and dynamic draught for the ships

Ships	In/ Out	Maximum Sinkage			Maximum Dynamic Draught		
		metres	point	% of Static Draught	metres	point	% of Static Draught
OOCL HOUSTON	out	1.11	Port Bilge	9.53	12.71	Port Bilge	109.53
SEAMAX STAMFORD	in	1.03	FP	9.91	12.14	AP	107.87
CMA CGM CHOPIN	in	1.32	FP	11.34	12.97	FP	111.34
	out	0.95	FP	9.53	11.93	AP	107.45
MOL EMISSARY	in	1.27	FP	11.66	12.77	AP	105.54
	out	1.12	FP	11.43	12.45	AP	108.24
SAFMARINE MAKUTU	in	1.17	Stbd Bilge	9.28	13.77	Stbd Bilge	109.28
	out	1.45	FP	13.22	12.48	Port Bilge	111.33
MOL PARAMOUNT	in	0.91	Stbd Bilge	7.96	12.30	Stbd Bilge	107.96
	out	0.98	FP	7.50	14.02	FP	107.50
CMA CGM LAMARTINE	out	1.11	Port Bilge	9.78	12.47	Port Bilge	109.78
OOCL BRISBANE	in	1.24	Port Bilge	10.73	12.92	AP	107.14
CMA CGM WAGNER	in	1.27	Stbd Bilge	11.81	12.38	AP	107.62

Nearly half of the transits have maximum sinkage at the bilge corners, and the other half at the bow. However, for a ship with static stern-down trim, e.g. SEAMAX STAMFORD inbound, CMA

CGM CHOPIN inbound and MOL EMISSARY inbound/outbound (see Appendix A), the FP or bilge corners having maximum sinkage may not be the closest point to the seabed. The stern can still have maximum dynamic draught due to its already close proximity to the seabed. Here, the dynamic draught at each location on the ship can be found by adding the static draught at that point to the sinkage at that point. The point on the ship with the maximum dynamic draught is the point most likely to hit the bottom, shown in Table 1. Maximum sinkage and dynamic draught are also expressed as a percentage of the static draught of the ships to compare the results to conventional information on ship UKC or navigation.

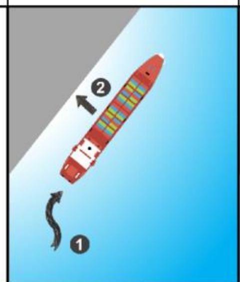
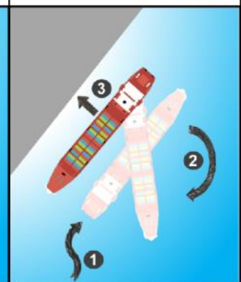
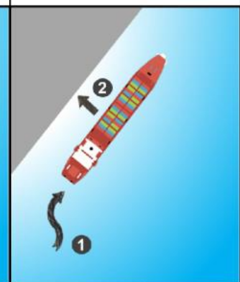
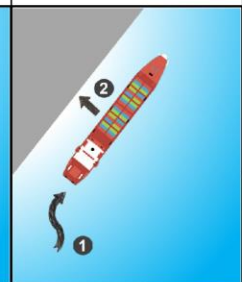
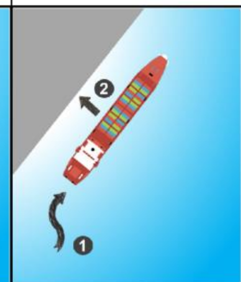
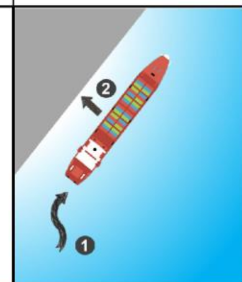
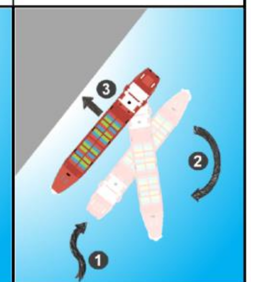
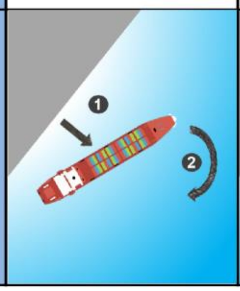
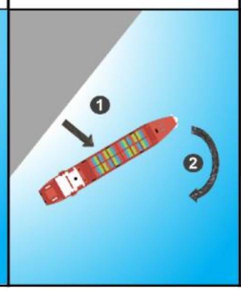
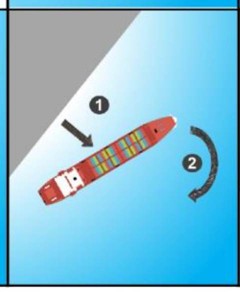
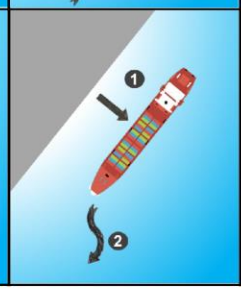
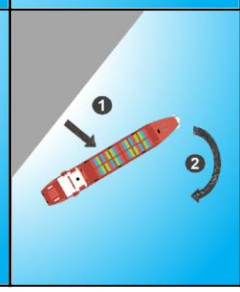
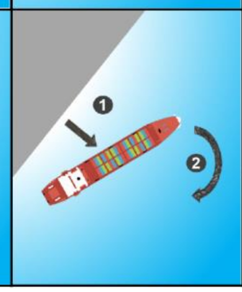
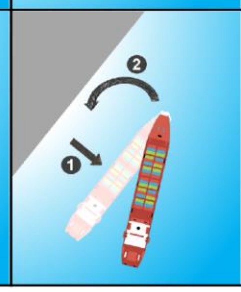
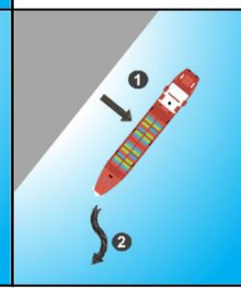
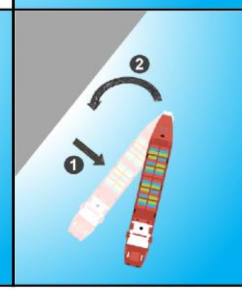
Calculated minimum real-time clearance in the Entrance Channel and Inner Harbour and Deep Water Channel, as well as the keel point where that occurs, are shown in Table 2.

Table 2. Calculated minimum under-keel clearance for the ships

Ships	In/ Out	UKC					
		Entrance Channel &Inner Harbour			Deep Water Channel		
		metres	point	% of Static Draught	metres	point	% of Static Draught
OOCL HOUSTON	out	3.33	FP	28.66	4.77	Stbd Bilge	41.08
SEAMAX STAMFORD	in	3.93	AP	34.97	5.05	AP	44.90
CMA CGM CHOPIN	in	3.54	Port Bilge	30.33	4.33	FP	37.21
	out	4.10	AP	36.94	5.45	AP	49.13
MOL EMISSARY	in	3.30	AP	27.29	4.63	AP	38.25
	out	3.76	AP	32.68	4.97	AP	43.21
SAFMARINE MAKUTU	in	2.47	Stbd Bilge	19.57	3.62	FP	28.72
	out	3.38	AP	29.64	4.51	FP	40.96
MOL PARAMOUNT	in	3.67	Stbd Bilge	32.26	4.75	Stbd Bilge	41.68
	out	2.05	FP	15.72	3.28	FP	25.12
CMA CGM LAMARTINE	out	3.35	AP	29.13	4.61	AP	40.11
OOCL BRISBANE	in	3.22	AP	26.70	4.38	AP	36.34
CMA CGM WAGNER	in	3.82	AP	33.20	4.92	AP	42.76

Generally, for the ships trimmed by the stern at departure or arrival time, the AP is the point closest to the seabed in both channels, but the ships with almost level static trim have their minimum UKC at the FP or the bilge corners. Note that the points closest to the seabed can be different in Table 1 and Table 2 because the maximum sinkage and dynamic draught for each ship have been captured through its whole transit, including sections out of the channels, whereas the minimum UKC for each ship has been calculated within the channels.

Appendix A – Details of the ships and transit conditions

	MSC ILONA	OOCL HOUSTON	SEAMAX STAMFORD	CMA CGM CHOPIN	MOL EMISSARY	SAFMARINE MAKUTU	MOL PARAMOUNT	CMA CGM LAMARTINE	OOCL BRISBANE	CMA CGM WAGNER
Ship Type	**Post-Panamax**	**Panamax**	**Post-Panamax**	**Post-Panamax**	**Panamax**	**Panamax**	**Post-Panamax**	**Post-Panamax**	**Panamax**	**Post-Panamax**
Capacity (TEU)	**6,750**	**4,578**	**4,896**	**5,782**	**5,100**	**4,154**	**6,350**	**6,574**	**4,578**	**5,782**
Year Built	2001	2007	2015	2004	2009	2007	2005	2009	2009	2004
L_{OA} (m)	300.00	260.05	250.00	277.28	294.13	292.08	293.19	299.20	260.05	277.28
L_{PP} (m)	286.56	244.80	238.35	263.00	283.20	277.00	276.00	286.70	244.80	263.00
Depth (m)	24.20	19.30	19.60	24.30	22.10	21.70	24.30	24.60	19.30	24.30
Beam (m)	40.00	32.25	37.30	40.00	32.20	32.25	40.00	40.00	32.25	40.00
Design Draught (m)	12.00	11.00	11.50	12.50	12.00	12.20	-	12.00	11.00	12.50
Summer Draught (m)	14.50	12.60	13.00	14.50	13.65	13.50	14.02	14.52	12.60	14.52
Displacement (ton)	112,639.60	67,248.80	79,702.00	96,757.00	87,855.00	82,287.00	99,620.00	110,445.10	67,248.80	96,997.00
Deadweight (ton)	85,890.30	50,585.20	59,918.00	73,234.60	67,407.00	61,407.50	72,968.00	85,446.50	50,574.90	73,331.20
Arrival Draught (m)	-	-	FP 12.35 Mid 12.42 AP 12.49	FP 10.00 Mid - AP 11.10	FP 9.80 Mid 10.50 AP 11.50	FP 11.00 Mid - AP 11.40	FP 13.04 Mid - AP 12.99	-	FP 10.00 Mid 10.20 AP 10.40	FP 10.00 Mid - AP 11.50
Departure Draught (m)	FP 12.35 Mid - AP 12.35	FP 11.60 Mid - AP 11.60	FP 10.40 Mid - AP 11.25	FP 11.65 Mid - AP 11.70	FP 10.90 Mid 11.40 AP 12.10	FP 12.60 Mid - AP 12.60	FP 11.39 Mid - AP 11.39	FP 11.20 Mid - AP 11.50	FP 11.02 Mid 11.54 AP 12.06	-
Berth No. (North Quay)	NQ No.7	NQ No.7	NQ No.9	NQ No.5	NQ No.7	NQ No.9	NQ No.7	NQ No.5	NQ No.9	NQ No.5
Berthing side (port or stbd)	port-side	port-side	port-side	starboard-side	port-side	port-side	port-side	starboard-side	port-side	starboard-side
Arrival Berthing	-	-						-		
Depature Unberthing										-

Appendix B – Wave (Sea and Swell) data

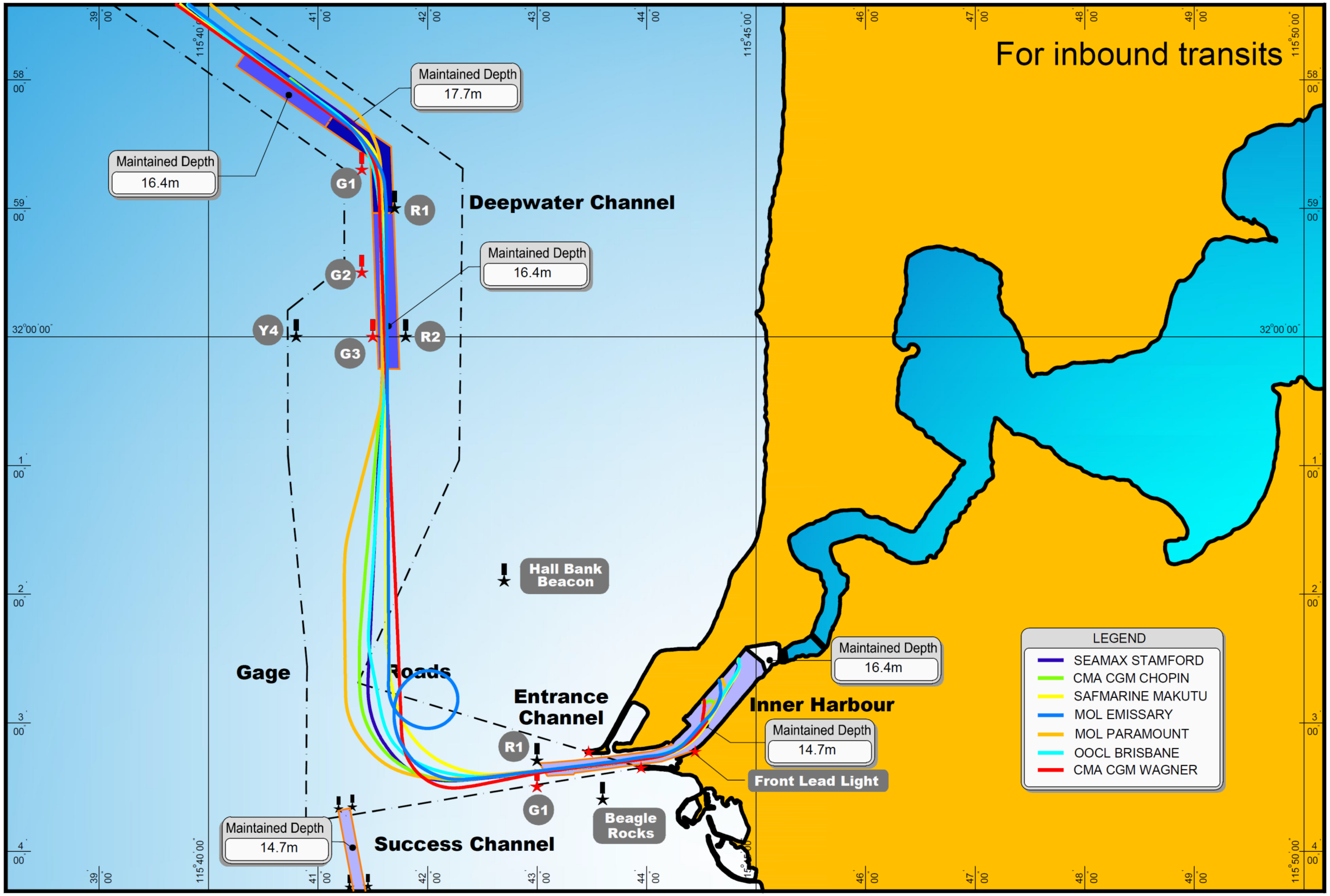
	OOCL HOUSTON	SEAMAX STAMFORD	CMA CGM CHOPIN	MOL EMISSARY	CMA CGM CHOPIN	MOL EMISSARY	SAFMARINE MAKUTU
In / Out	out	in	in	in	out	out	in
Measurement Date and Time	16/04/2016 11:11:06 PM ~ 11:57:20 PM	17/04/2016 4:27:32 AM ~ 5:46:56 AM	18/04/2016 4:19:38 AM ~ 5:36:03 AM	18/04/2016 6:24:35 PM ~ 7:51:33 PM	18/04/2016 8:21:45 PM ~ 9:16:32 PM	19/04/2016 9:55:24 PM ~ 11:21:16 PM	20/04/2016 8:56:18 PM ~ 10:09:07 PM
Wave (Sea)	11:00 PM H_s 0.34 T_s 3.06 T_P 6.06	4:15 AM H_s 0.28 T_s 3.70 T_P 7.55	4:15 AM H_s 0.51 T_s 3.20 T_P 4.73	6:15 PM H_s 0.40 T_s 3.79 T_P 7.21	8:15 PM H_s 0.46 T_s 3.65 T_P 6.61	9:45 PM H_s 0.36 T_s 3.08 T_P 6.06	8:45 PM H_s 0.63 T_s 3.39 T_P 4.94
	11:15 PM H_s 0.35 T_s 3.08 T_P 7.55	4:30 AM H_s 0.28 T_s 3.72 T_P 6.69	4:30 AM H_s 0.50 T_s 3.18 T_P 3.81	6:30 PM H_s 0.41 T_s 3.71 T_P 6.75	8:30 PM H_s 0.46 T_s 3.55 T_P 7.05	10:00 PM H_s 0.35 T_s 3.11 T_P 7.80	9:00 PM H_s 0.62 T_s 3.38 T_P 3.83
	11:30 PM H_s 0.35 T_s 3.12 T_P 6.84	4:45 AM H_s 0.29 T_s 3.77 T_P 6.43	4:45 AM H_s 0.51 T_s 3.22 T_P 3.81	6:45 PM H_s 0.44 T_s 3.71 T_P 6.69	8:45 PM H_s 0.47 T_s 3.56 T_P 7.02	10:15 PM H_s 0.35 T_s 3.17 T_P 7.05	9:15 PM H_s 0.62 T_s 3.44 T_P 4.41
	11:45 PM H_s 0.34 T_s 2.98 T_P 7.66	5:00 AM H_s 0.29 T_s 3.76 T_P 6.56	5:00 AM H_s 0.50 T_s 3.16 T_P 2.62	7:00 PM H_s 0.45 T_s 3.53 T_P 7.27	9:00 PM H_s 0.46 T_s 3.58 T_P 6.75	10:30 PM H_s 0.36 T_s 3.08 T_P 7.08	9:30 PM H_s 0.63 T_s 3.49 T_P 5.00
	12:00 AM H_s 0.33 T_s 3.02 T_P 7.62	5:15 AM H_s 0.29 T_s 3.88 T_P 7.11	5:15 AM H_s 0.50 T_s 3.16 T_P 5.18	7:15 PM H_s 0.48 T_s 3.50 T_P 6.35	9:15 PM H_s 0.48 T_s 3.68 T_P 7.17	10:45 PM H_s 0.38 T_s 3.06 T_P 3.16	9:45 PM H_s 0.63 T_s 3.45 T_P 4.85
		5:30 AM H_s 0.29 T_s 3.91 T_P 6.75	5:30 AM H_s 0.51 T_s 3.12 T_P 3.71	7:30 PM H_s 0.47 T_s 3.52 T_P 7.11	9:30 PM H_s 0.48 T_s 3.53 T_P 6.48	11:00 PM H_s 0.39 T_s 3.09 T_P 3.04	10:00 PM H_s 0.62 T_s 3.47 T_P 5.06
		5:45 AM H_s 0.32 T_s 3.95 T_P 5.21	5:45 AM H_s 0.51 T_s 3.12 T_P 4.72	7:45 PM H_s 0.45 T_s 3.32 T_P 6.90		11:15 PM H_s 0.40 T_s 3.14 T_P 6.25	10:15 PM H_s 0.60 T_s 3.48 T_P 3.80
		6:00 AM H_s 0.33 T_s 3.97 T_P 7.41		8:00 PM H_s 0.47 T_s 3.44 T_P 7.37		11:30 PM H_s 0.41 T_s 3.14 T_P 3.19	
Wave (Swell)	11:00 PM H_s 0.36 T_s 12.25 T_P 11.94	4:15 AM H_s 0.33 T_s 12.84 T_P 17.39	4:15 AM H_s 0.46 T_s 13.48 T_P 15.24	6:15 PM H_s 0.54 T_s 12.62 T_P 15.38	8:15 PM H_s 0.58 T_s 12.45 T_P 13.45	9:45 PM H_s 0.41 T_s 11.89 T_P 13.11	8:45 PM H_s 0.33 T_s 12.39 T_P 12.60
	11:15 PM H_s 0.33 T_s 12.38 T_P 17.78	4:30 AM H_s 0.34 T_s 13.07 T_P 18.39	4:30 AM H_s 0.42 T_s 13.46 T_P 14.68	6:30 PM H_s 0.55 T_s 12.73 T_P 14.29	8:30 PM H_s 0.60 T_s 12.19 T_P 13.45	10:00 PM H_s 0.43 T_s 12.11 T_P 13.91	9:00 PM H_s 0.33 T_s 12.43 T_P 13.68
	11:30 PM H_s 0.35 T_s 12.38 T_P 15.09	4:45 AM H_s 0.38 T_s 13.12 T_P 14.55	4:45 AM H_s 0.41 T_s 13.19 T_P 15.53	6:45 PM H_s 0.57 T_s 12.82 T_P 14.41	8:45 PM H_s 0.61 T_s 12.40 T_P 13.56	10:15 PM H_s 0.48 T_s 12.18 T_P 13.91	9:15 PM H_s 0.35 T_s 12.40 T_P 12.31
	11:45 PM H_s 0.38 T_s 12.62 T_P 13.11	5:00 AM H_s 0.40 T_s 12.97 T_P 17.02	5:00 AM H_s 0.40 T_s 13.25 T_P 12.90	7:00 PM H_s 0.51 T_s 12.60 T_P 15.09	9:00 PM H_s 0.56 T_s 12.74 T_P 13.56	10:30 PM H_s 0.44 T_s 12.12 T_P 14.68	9:30 PM H_s 0.31 T_s 12.47 T_P 13.91
	12:00 AM H_s 0.36 T_s 12.23 T_P 14.29	5:15 AM H_s 0.40 T_s 12.76 T_P 16.84	5:15 AM H_s 0.45 T_s 13.34 T_P 15.84	7:15 PM H_s 0.47 T_s 12.46 T_P 11.35	9:15 PM H_s 0.59 T_s 12.54 T_P 14.68	10:45 PM H_s 0.41 T_s 12.43 T_P 14.68	9:45 PM H_s 0.31 T_s 12.47 T_P 13.56
		5:30 AM H_s 0.40 T_s 12.45 T_P 11.85	5:30 AM H_s 0.44 T_s 13.67 T_P 16.00	7:30 PM H_s 0.55 T_s 12.91 T_P 14.16	9:30 PM H_s 0.60 T_s 12.57 T_P 11.43	11:00 PM H_s 0.40 T_s 12.15 T_P 13.22	10:00 PM H_s 0.32 T_s 12.28 T_P 13.91
		5:45 AM H_s 0.43 T_s 12.99 T_P 14.81	5:45 AM H_s 0.40 T_s 13.68 T_P 15.38	7:45 PM H_s 0.55 T_s 12.30 T_P 12.50		11:15 PM H_s 0.46 T_s 12.29 T_P 13.22	10:15 PM H_s 0.30 T_s 11.93 T_P 12.03
		6:00 AM H_s 0.42 T_s 13.16 T_P 14.68		8:00 PM H_s 0.61 T_s 12.48 T_P 12.50		11:30 PM H_s 0.46 T_s 12.21 T_P 13.45	

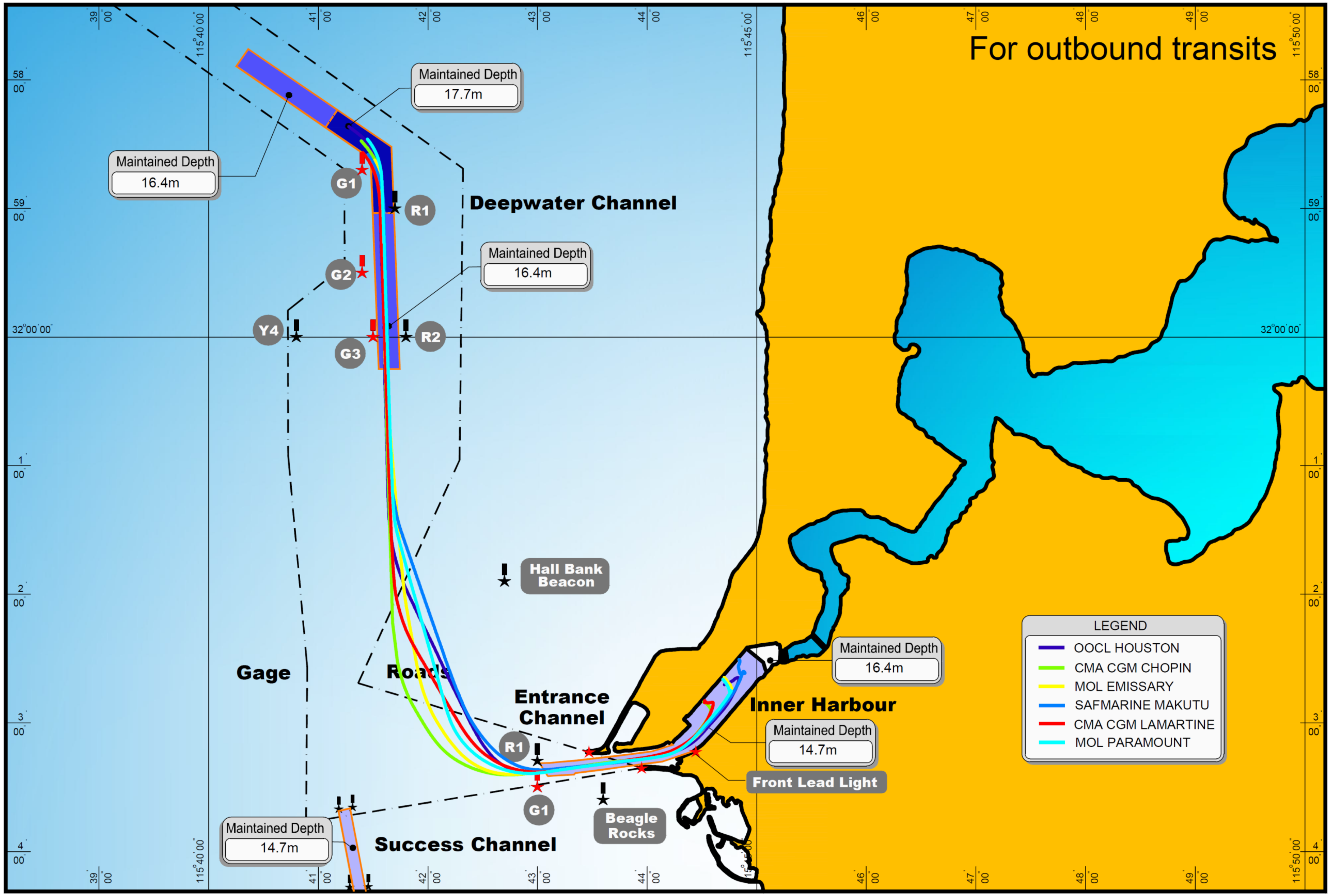
	MOL PARAMOUNT	SAFMARINE MAKUTU	CMA CGM LAMARTINE	MOL PARAMOUNT	OOCL BRISBANE	CMA CGM WAGNER
In / Out	in	out	out	out	in	in
Measurement Date and Time	21/04/2016 3:11:24 AM ~ 4:32:32 AM	21/04/2016 4:00:00 PM ~ 5:16:55 PM	22/04/2016 2:20:00 PM ~ 3:11:57 PM	22/04/2016 6:55:26 PM ~ 8:12:00 PM	24/04/2016 9:05:16 PM ~ 10:16:30 PM	25/04/2016 4:12:50 AM ~ 5:31:10 AM
Wave (Sea)	3:00 AM H_s 0.55 T_s 3.60 T_P 5.76	4:00 PM H_s 0.58 T_s 3.73 T_P 5.63	2:15 PM H_s 0.54 T_s 3.66 T_P 3.96	6:45 PM H_s 0.61 T_s 3.46 T_P 5.10	9:00 PM H_s 0.39 T_s 3.22 T_P 7.34	4:00 AM H_s 0.42 T_s 2.82 T_P 7.66
	3:15 AM H_s 0.55 T_s 3.49 T_P 5.76	4:15 PM H_s 0.56 T_s 3.83 T_P 6.58	2:30 PM H_s 0.56 T_s 3.78 T_P 4.30	7:00 PM H_s 0.62 T_s 3.39 T_P 5.10	9:15 PM H_s 0.39 T_s 2.91 T_P 6.58	4:15 AM H_s 0.42 T_s 2.87 T_P 7.77
	3:30 AM H_s 0.53 T_s 3.46 T_P 5.84	4:30 PM H_s 0.55 T_s 3.89 T_P 7.27	2:45 PM H_s 0.56 T_s 3.80 T_P 4.18	7:15 PM H_s 0.63 T_s 3.40 T_P 5.25	9:30 PM H_s 0.40 T_s 2.86 T_P 6.61	4:30 AM H_s 0.40 T_s 2.88 T_P 7.80
	3:45 AM H_s 0.53 T_s 3.66 T_P 5.42	4:45 PM H_s 0.56 T_s 3.96 T_P 6.02	3:00 PM H_s 0.55 T_s 3.74 T_P 4.11	7:30 PM H_s 0.64 T_s 3.30 T_P 7.66	9:45 PM H_s 0.42 T_s 2.97 T_P 7.37	4:45 AM H_s 0.38 T_s 2.90 T_P 7.84
	4:00 AM H_s 0.54 T_s 3.64 T_P 5.88	5:00 PM H_s 0.54 T_s 3.97 T_P 5.44	3:15 PM H_s 0.54 T_s 3.76 T_P 7.80	7:45 PM H_s 0.71 T_s 3.30 T_P 3.01	10:00 PM H_s 0.41 T_s 2.86 T_P 2.22	5:00 AM H_s 0.36 T_s 2.97 T_P 7.51
	4:15 AM H_s 0.55 T_s 3.70 T_P 5.76	5:15 PM H_s 0.55 T_s 3.84 T_P 6.72		8:00 PM H_s 0.75 T_s 3.34 T_P 3.09	10:15 PM H_s 0.41 T_s 2.79 T_P 6.56	5:15 AM H_s 0.35 T_s 2.93 T_P 7.48
	4:30 AM H_s 0.53 T_s 3.62 T_P 5.76	5:30 PM H_s 0.52 T_s 3.82 T_P 6.99		8:15 PM H_s 0.75 T_s 3.29 T_P 3.19	10:30 PM H_s 0.38 T_s 2.89 T_P 7.84	5:30 AM H_s 0.36 T_s 2.83 T_P 7.41
	4:45 AM H_s 0.52 T_s 3.63 T_P 5.73					5:45 AM H_s 0.37 T_s 2.78 T_P 7.44
Wave (Swell)	3:00 AM H_s 0.25 T_s 12.37 T_P 13.79	4:00 PM H_s 0.42 T_s 11.35 T_P 11.11	2:15 PM H_s 0.50 T_s 12.00 T_P 15.69	6:45 PM H_s 0.51 T_s 12.57 T_P 17.02	9:00 PM H_s 0.48 T_s 11.60 T_P 14.16	4:00 AM H_s 0.58 T_s 12.57 T_P 12.40
	3:15 AM H_s 0.26 T_s 12.29 T_P 13.79	4:15 PM H_s 0.39 T_s 11.51 T_P 11.51	2:30 PM H_s 0.49 T_s 11.65 T_P 16.33	7:00 PM H_s 0.53 T_s 12.42 T_P 16.00	9:15 PM H_s 0.48 T_s 12.04 T_P 12.40	4:15 AM H_s 0.54 T_s 12.39 T_P 12.70
	3:30 AM H_s 0.29 T_s 12.22 T_P 12.80	4:30 PM H_s 0.41 T_s 11.28 T_P 12.21	2:45 PM H_s 0.50 T_s 11.65 T_P 16.84	7:15 PM H_s 0.51 T_s 12.66 T_P 16.00	9:30 PM H_s 0.51 T_s 11.83 T_P 12.21	4:30 AM H_s 0.53 T_s 12.35 T_P 13.01
	3:45 AM H_s 0.29 T_s 12.09 T_P 13.79	4:45 PM H_s 0.39 T_s 11.50 T_P 11.11	3:00 PM H_s 0.49 T_s 11.89 T_P 12.12	7:30 PM H_s 0.49 T_s 12.44 T_P 16.67	9:45 PM H_s 0.53 T_s 11.96 T_P 14.16	4:45 AM H_s 0.56 T_s 12.50 T_P 16.16
	4:00 AM H_s 0.25 T_s 11.86 T_P 12.90	5:00 PM H_s 0.41 T_s 11.53 T_P 12.03	3:15 PM H_s 0.49 T_s 11.73 T_P 16.49	7:45 PM H_s 0.50 T_s 12.48 T_P 16.67	10:00 PM H_s 0.50 T_s 11.84 T_P 14.29	5:00 AM H_s 0.56 T_s 12.94 T_P 14.29
	4:15 AM H_s 0.24 T_s 11.97 T_P 13.33	5:15 PM H_s 0.38 T_s 11.19 T_P 11.27		8:00 PM H_s 0.52 T_s 12.28 T_P 16.16	10:15 PM H_s 0.54 T_s 11.77 T_P 11.43	5:15 AM H_s 0.52 T_s 13.45 T_P 17.58
	4:30 AM H_s 0.28 T_s 12.30 T_P 13.79	5:30 PM H_s 0.41 T_s 11.35 T_P 11.19		8:15 PM H_s 0.51 T_s 12.07 T_P 15.84	10:30 PM H_s 0.54 T_s 11.37 T_P 12.60	5:30 AM H_s 0.58 T_s 13.08 T_P 12.31
	4:45 AM H_s 0.27 T_s 12.15 T_P 13.79					5:45 AM H_s 0.62 T_s 13.69 T_P 16.49

Appendix C – Tidal and wind data

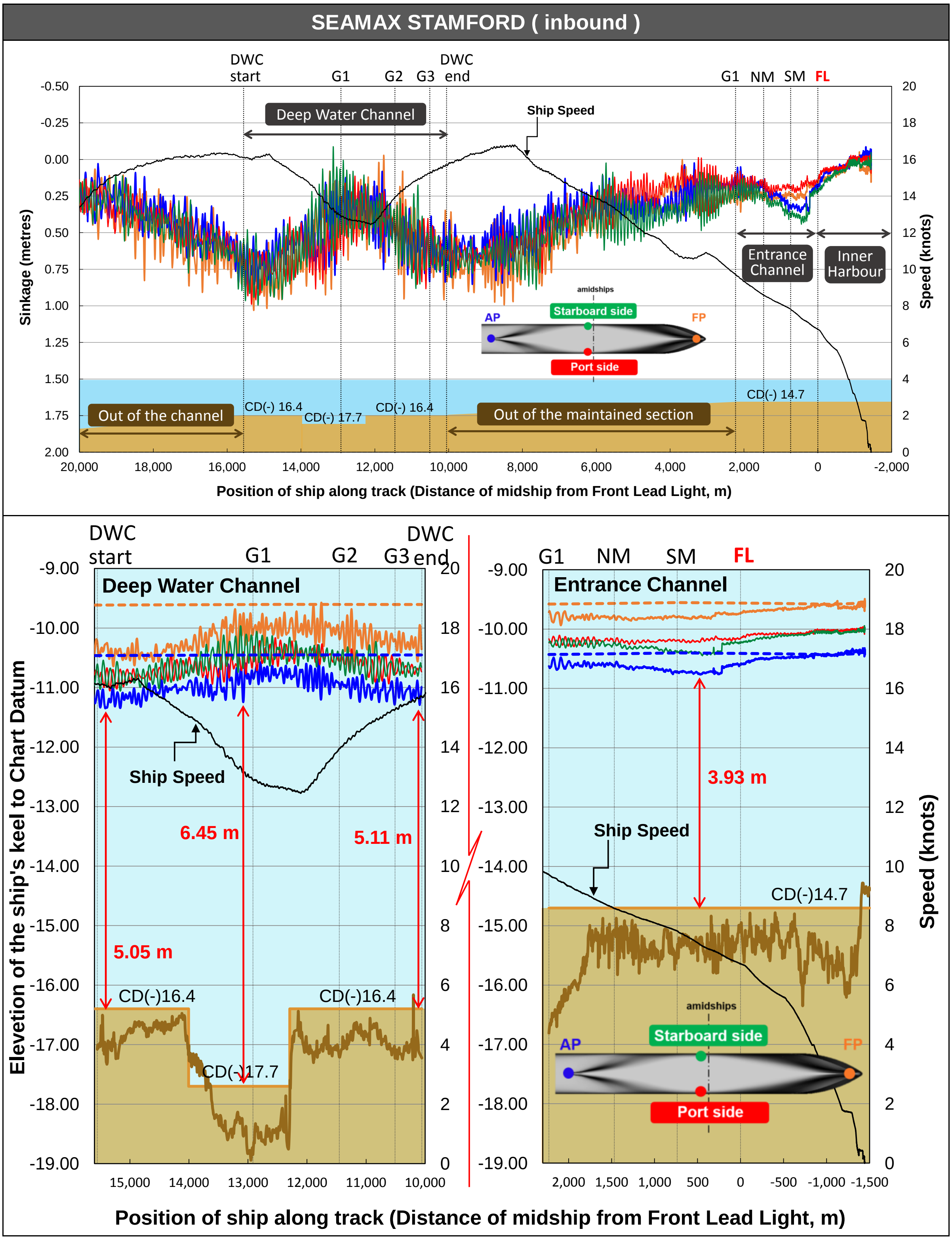
	OOCL HOUSTON	SEAMAX STAMFORD	CMA CGM CHOPIN	MOL EMISSARY	CMA CGM CHOPIN	MOL EMISSARY	SAFMARINE MAKUTU	MOL PARAMOUNT	SAFMARINE MAKUTU	CMA CGM LAMARTINE	MOL PARAMOUNT	OOCL BRISBANE	CMA CGM WAGNER
In / Out	out	in	in	in	out	out	in	in	out	out	out	in	in
Measurement Date and Time	16/04/2016 11:11:06 PM ~ 11:57:20 PM	17/04/2016 4:27:32 AM ~ 5:46:56 AM	18/04/2016 4:19:38 AM ~ 5:36:03 AM	18/04/2016 6:24:35 PM ~ 7:51:33 PM	18/04/2016 8:21:45 PM ~ 9:16:32 PM	19/04/2016 9:55:24 PM ~ 11:21:16 PM	20/04/2016 8:56:18 PM ~ 10:09:07 PM	21/04/2016 3:11:24 AM ~ 4:32:32 AM	21/04/2016 4:00:00 PM ~ 5:16:55 PM	22/04/2016 2:20:00 PM ~ 3:11:57 PM	22/04/2016 6:55:26 PM ~ 8:12:00 PM	24/04/2016 9:05:16 PM ~ 10:16:30 PM	25/04/2016 4:12:50 AM ~ 5:31:10 AM
Tide	11:10 PM 0.846	4:25 AM 0.771	4:15 AM 0.842	6:20 PM 1.010	8:20 PM 1.032	9:55 PM 0.918	8:55 PM 0.781	3:10 AM 0.615	4:00 PM 0.580	2:20 PM 0.658	6:55 PM 0.655	9:05 PM 0.852	4:10 AM 0.912
	11:15 PM 0.838	4:30 AM 0.774	4:20 AM 0.826	6:25 PM 1.005	8:25 PM 1.044	10:00 PM 0.913	9:00 PM 0.775	3:15 AM 0.624	4:05 PM 0.586	2:25 PM 0.647	7:00 PM 0.646	9:10 PM 0.871	4:15 AM 0.906
	11:20 PM 0.845	4:35 AM 0.781	4:25 AM 0.821	6:30 PM 1.002	8:30 PM 1.042	10:05 PM 0.904	9:05 PM 0.769	3:20 AM 0.631	4:10 PM 0.590	2:30 PM 0.635	7:05 PM 0.651	9:15 PM 0.869	4:20 AM 0.901
	11:25 PM 0.796	4:40 AM 0.790	4:30 AM 0.833	6:35 PM 0.992	8:35 PM 1.037	10:10 PM 0.899	9:10 PM 0.768	3:25 AM 0.639	4:15 PM 0.583	2:35 PM 0.621	7:10 PM 0.658	9:20 PM 0.853	4:25 AM 0.879
	11:30 PM 0.849	4:45 AM 0.798	4:35 AM 0.838	6:40 PM 0.999	8:40 PM 1.036	10:15 PM 0.888	9:15 PM 0.771	3:30 AM 0.643	4:20 PM 0.586	2:40 PM 0.559	7:15 PM 0.671	9:25 PM 0.851	4:30 AM 0.888
	11:35 PM 0.841	4:50 AM 0.796	4:40 AM 0.819	6:45 PM 1.006	8:45 PM 0.997	10:20 PM 0.883	9:20 PM 0.781	3:35 AM 0.651	4:25 PM 0.578	2:45 PM 0.617	7:20 PM 0.674	9:30 PM 0.875	4:35 AM 0.898
	11:40 PM 0.838	4:55 AM 0.797	4:45 AM 0.810	6:50 PM 0.989	8:50 PM 1.021	10:25 PM 0.883	9:25 PM 0.776	3:40 AM 0.661	4:30 PM 0.581	2:50 PM 0.612	7:25 PM 0.681	9:35 PM 0.867	4:40 AM 0.890
	11:45 PM 0.823	5:00 AM 0.803	4:50 AM 0.820	6:55 PM 0.975	8:55 PM 1.032	10:30 PM 0.877	9:30 PM 0.766	3:45 AM 0.662	4:35 PM 0.573	2:55 PM 0.610	7:30 PM 0.702	9:40 PM 0.851	4:45 AM 0.890
	11:50 PM 0.825	5:05 AM 0.810	4:55 AM 0.848	7:00 PM 0.975	9:00 PM 0.986	10:35 PM 0.869	9:35 PM 0.764	3:50 AM 0.657	4:40 PM 0.570	3:00 PM 0.590	7:35 PM 0.660	9:45 PM 0.845	4:55 AM 0.889
	11:55 PM 0.822	5:10 AM 0.824	5:00 AM 0.791	7:05 PM 0.988	9:05 PM 0.964	10:40 PM 0.860	9:40 PM 0.770	3:55 AM 0.663	4:45 PM 0.571	3:05 PM 0.606	7:40 PM 0.711	9:50 PM 0.892	5:35 AM 0.964
	12:00 AM 0.808	5:15 AM 0.848	5:05 AM 0.803	7:10 PM 1.024	9:10 PM 0.981	10:45 PM 0.852	9:45 PM 0.828	4:00 AM 0.667	4:50 PM 0.546	3:10 PM 0.619	7:45 PM 0.722	9:55 PM 0.881	
		5:20 AM 0.835	5:10 AM 0.816	7:15 PM 1.038	9:15 PM 0.966	10:50 PM 0.819	9:50 PM 0.806	4:05 AM 0.671	4:55 PM 0.581	3:15 PM 0.633	7:50 PM 0.702	10:00 PM 0.926	
		5:25 AM 0.818	5:15 AM 0.847	7:20 PM 1.028	9:20 PM 0.983	10:55 PM 0.848	9:55 PM 0.770	4:10 AM 0.658	5:00 PM 0.613		7:55 PM 0.669	10:05 PM 0.889	
		5:30 AM 0.834	5:20 AM 0.853	7:25 PM 1.026		11:00 PM 0.869	10:00 PM 0.768	4:15 AM 0.637	5:05 PM 0.581		8:00 PM 0.685	10:10 PM 0.887	
		5:35 AM 0.855	5:25 AM 0.850	7:30 PM 0.968		11:05 PM 0.862	10:05 PM 0.773	4:20 AM 0.646	5:10 PM 0.556		8:05 PM 0.707	10:15 PM 0.891	
		5:40 AM 0.860	5:30 AM 0.855	7:35 PM 1.001		11:10 PM 0.845	10:10 PM 0.751	4:25 AM 0.649	5:15 PM 0.566		8:10 PM 0.711	10:20 PM 0.879	
		5:45 AM 0.851	5:35 AM 0.854	7:40 PM 1.018		11:15 PM 0.836		4:30 AM 0.646	5:20 PM 0.570		8:15 PM 0.718		
		5:50 AM 0.837	5:40 AM 0.875	7:45 PM 1.049		11:20 PM 0.819		4:35 AM 0.650					
				7:50 PM 1.051		11:25 PM 0.801							
				7:55 PM 1.039									
Wind	Northerly 5 knots	Calm	Not recorded	Westerly 10 knots	Westerly 10 knots	South-westerly 15 knots	South-westerly 15 knots	Easterly 10 knots	Easterly 10 knots	Easterly 10 knots	Easterly 5 knots	North-westerly 5 - 10 knots	North-westerly 10 - 15 knots

Appendix D – Measured ship tracks

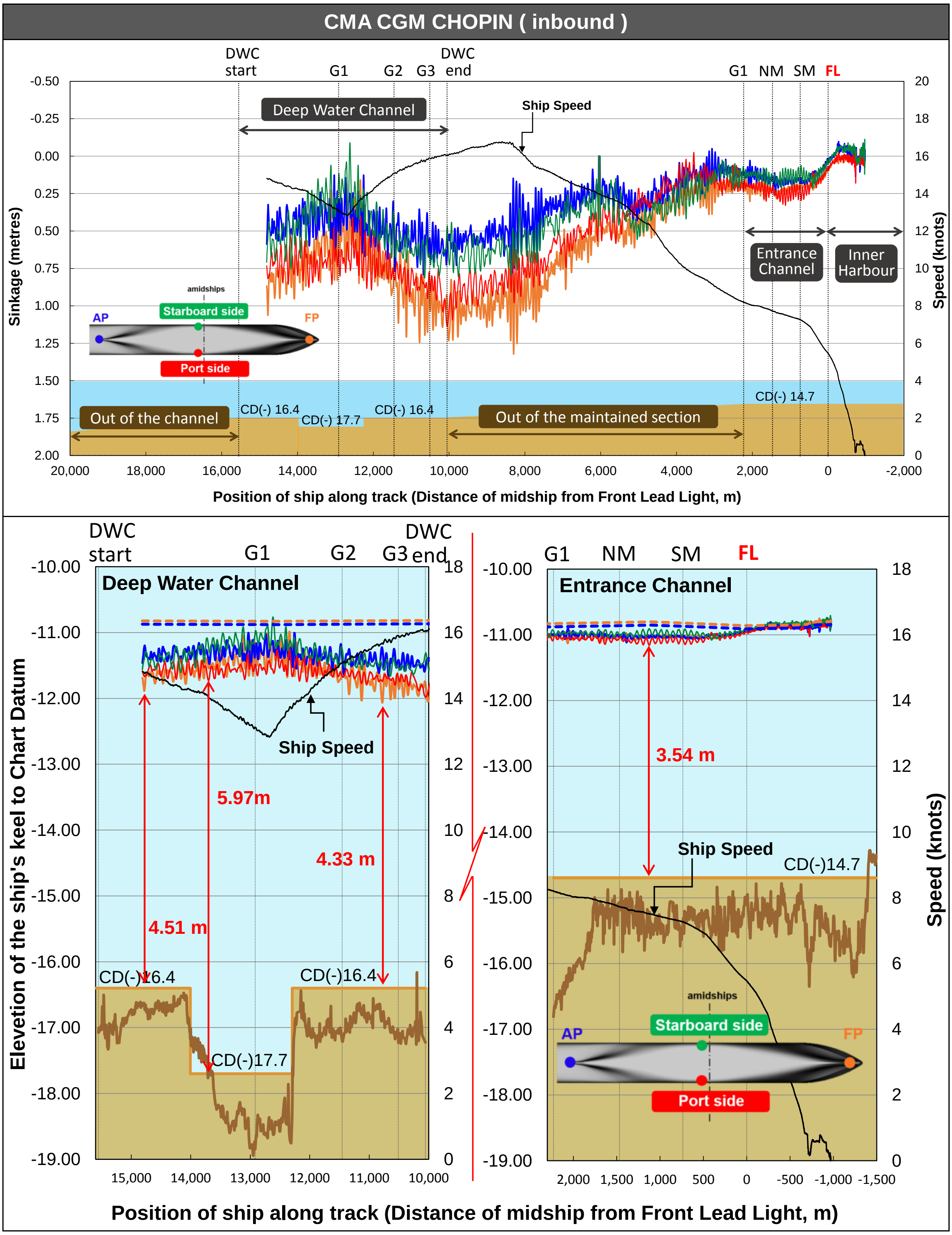



For outbound transits
Maintained Depth 17.7m
Maintained Depth 16.4m
Deepwater Channel
Maintained Depth 16.4m
G1
R1
G2
Y4
G3
R2
Hall Bank Beacon
Gage
Roads
Entrance Channel
Inner Harbour
Maintained Depth 16.4m
Maintained Depth 14.7m
Front Lead Light
R1
G1
Beagle Rocks
Maintained Depth 14.7m
Success Channel
LEGEND
OOCL HOUSTON
CMA CGM CHOPIN
MOL EMISSARY
SAFMARINE MAKUTU
CMA CGM LAMARTINE
MOL PARAMOUNT
32°00'00'
115°40'00'
115°45'00'
115°50'00'

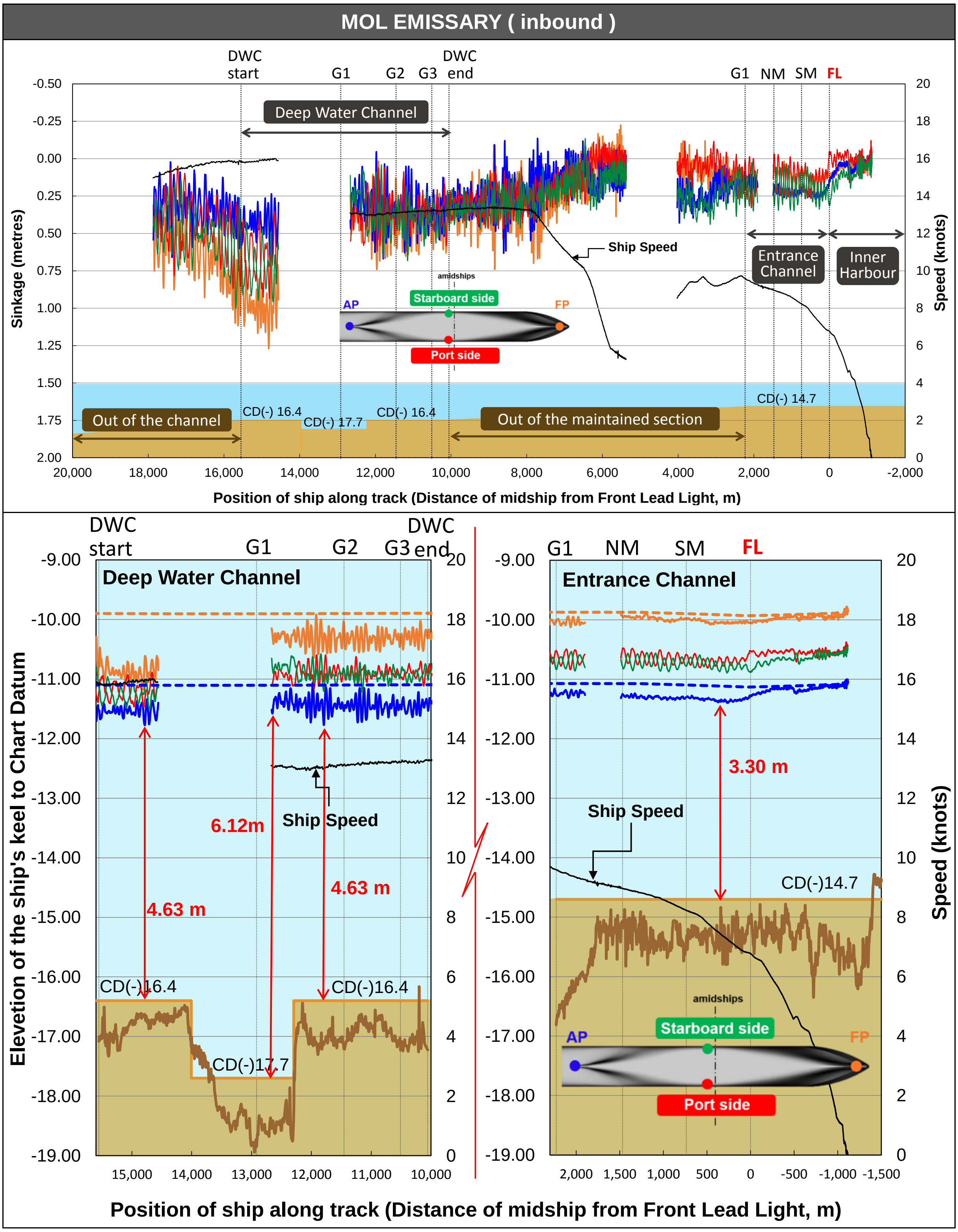
Appendix E – Graphical results



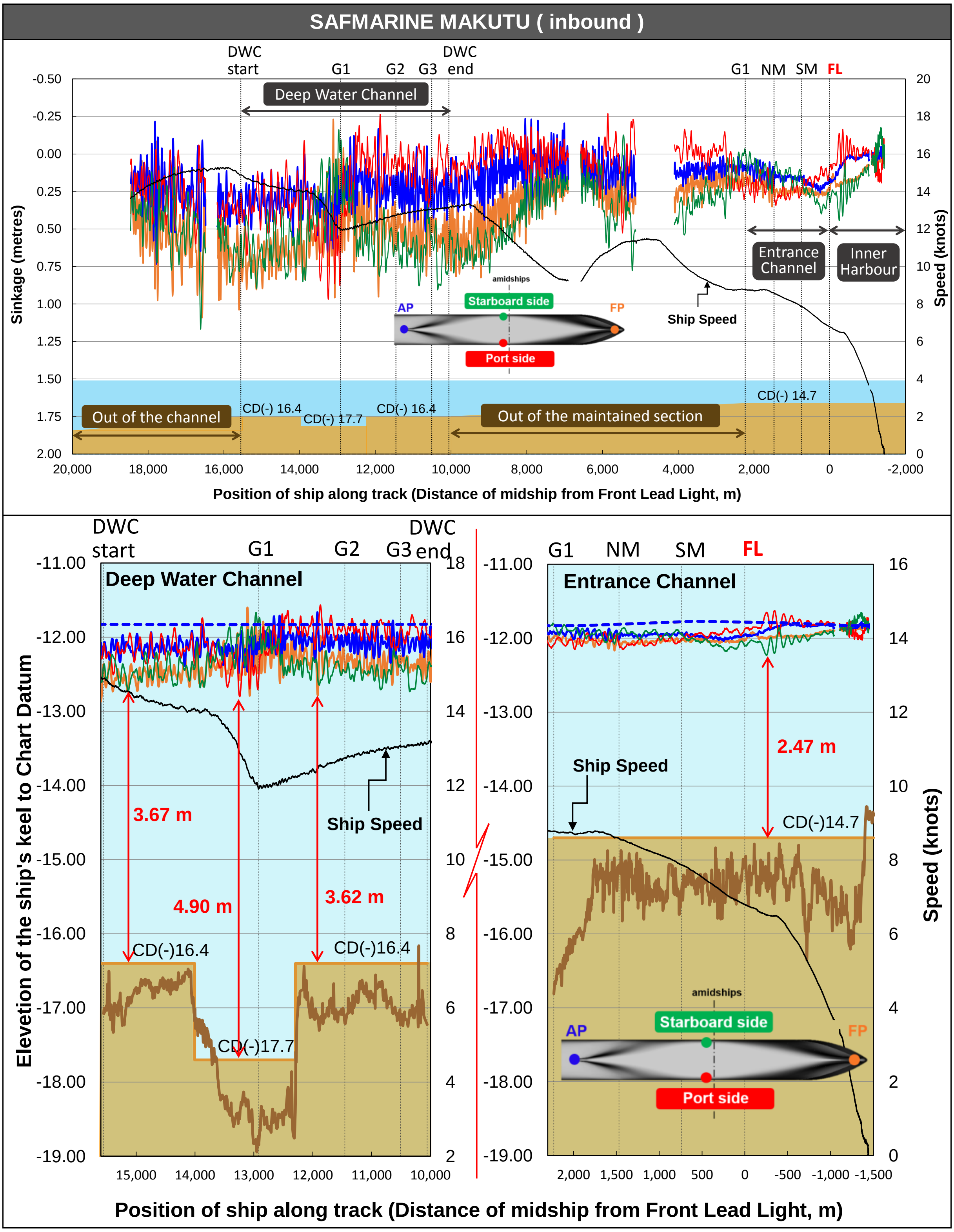
<Top> Measured sinkage (positive downward) at four points. Chart datum depths (not to scale) also shown.
<Bottom> Elevation of the ship's keel relative to chart datum. Broken lines are elevations of the FP and AP including changes in tide only, i.e. their static position, not including squat and wave-induced motions. A flat seabed line is based on the charted depth on AUS112, and a fluctuating seabed line is the actual survey line provided by Fremantle Ports.



<Top> Measured sinkage (positive downward) at four points. Chart datum depths (not to scale) also shown.
<Bottom> Elevation of the ship's keel relative to chart datum. Broken lines are elevations of the FP and AP including changes in tide only, i.e. their static position, not including squat and wave-induced motions. A flat seabed line is based on the charted depth on AUS112, and a fluctuating seabed line is the actual survey line provided by Fremantle Ports.

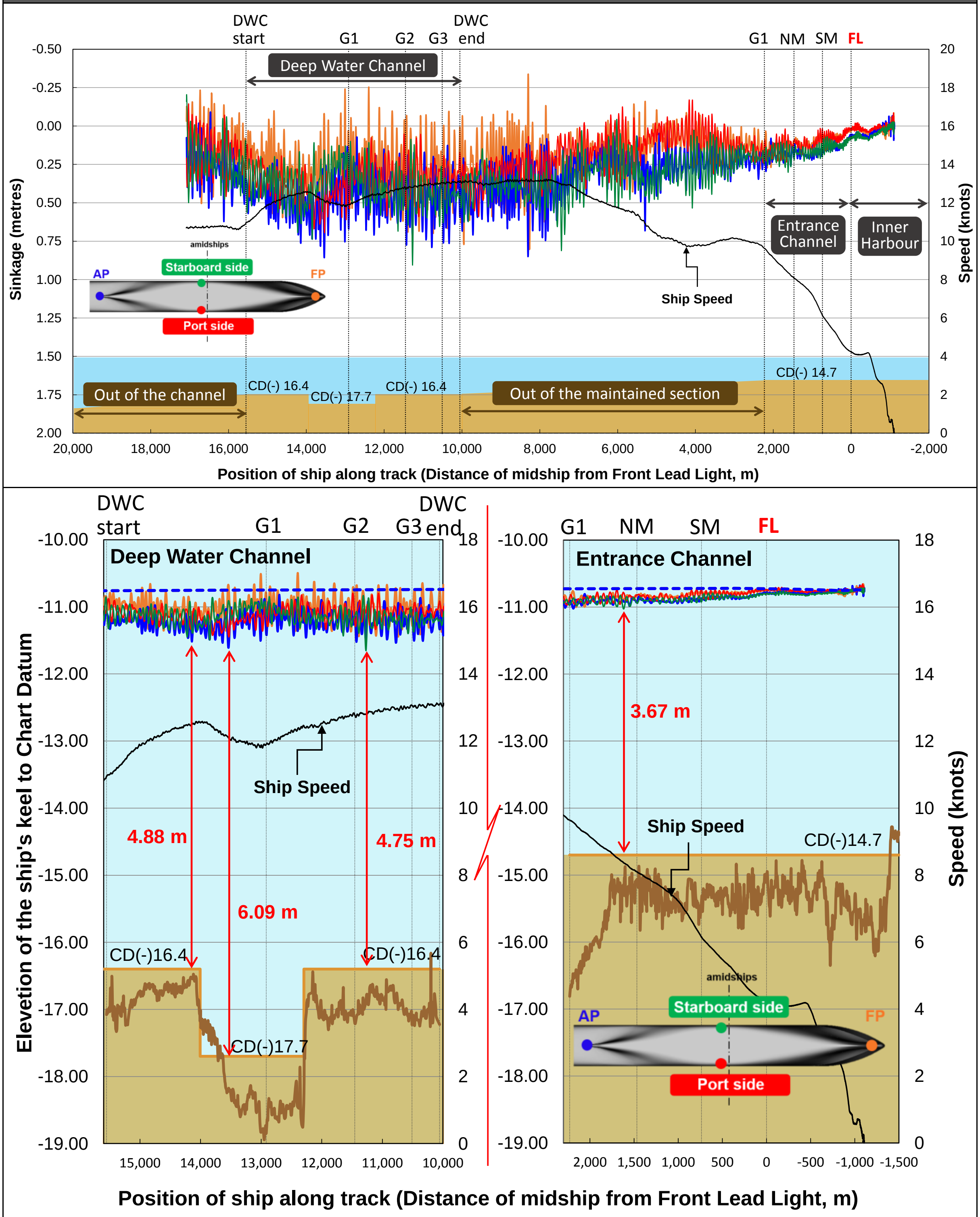


<Top> Measured sinkage (positive downward) at four points. Chart datum depths (not to scale) also shown. **<Bottom>** Elevation of the ship's keel relative to chart datum. Broken lines are elevations of the FP and AP including changes in tide only, i.e. their static position, not including squat and wave-induced motions. A flat seabed line is based on the charted depth on AUS112, and a fluctuating seabed line is the actual survey line provided by Fremantle Ports.

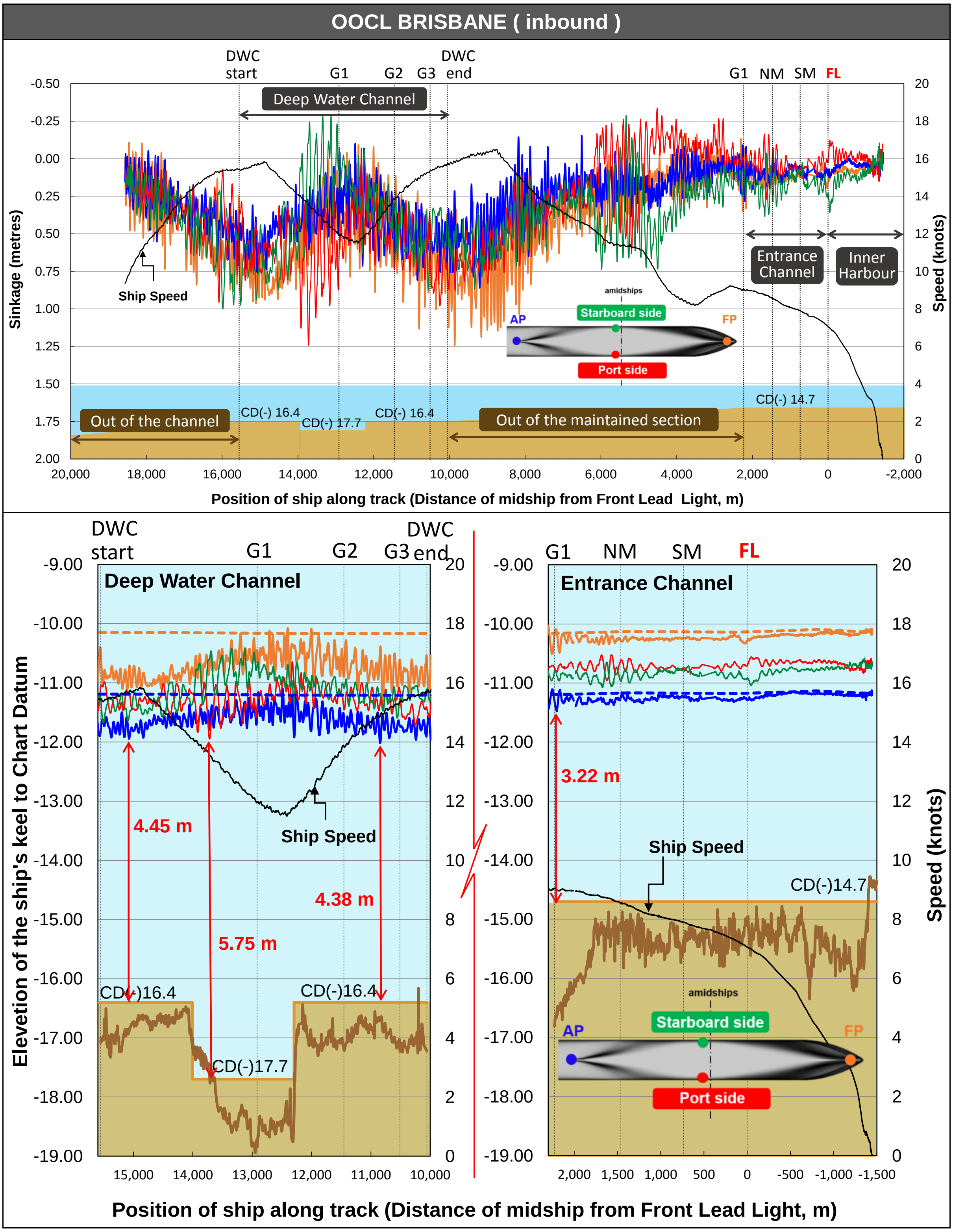


<Top> Measured sinkage (positive downward) at four points. Chart datum depths (not to scale) also shown.
<Bottom> Elevation of the ship's keel relative to chart datum. Broken lines are elevations of the FP and AP including changes in tide only, i.e. their static position, not including squat and wave-induced motions. A flat seabed line is based on the charted depth on AUS112, and a fluctuating seabed line is the actual survey line provided by Fremantle Ports.

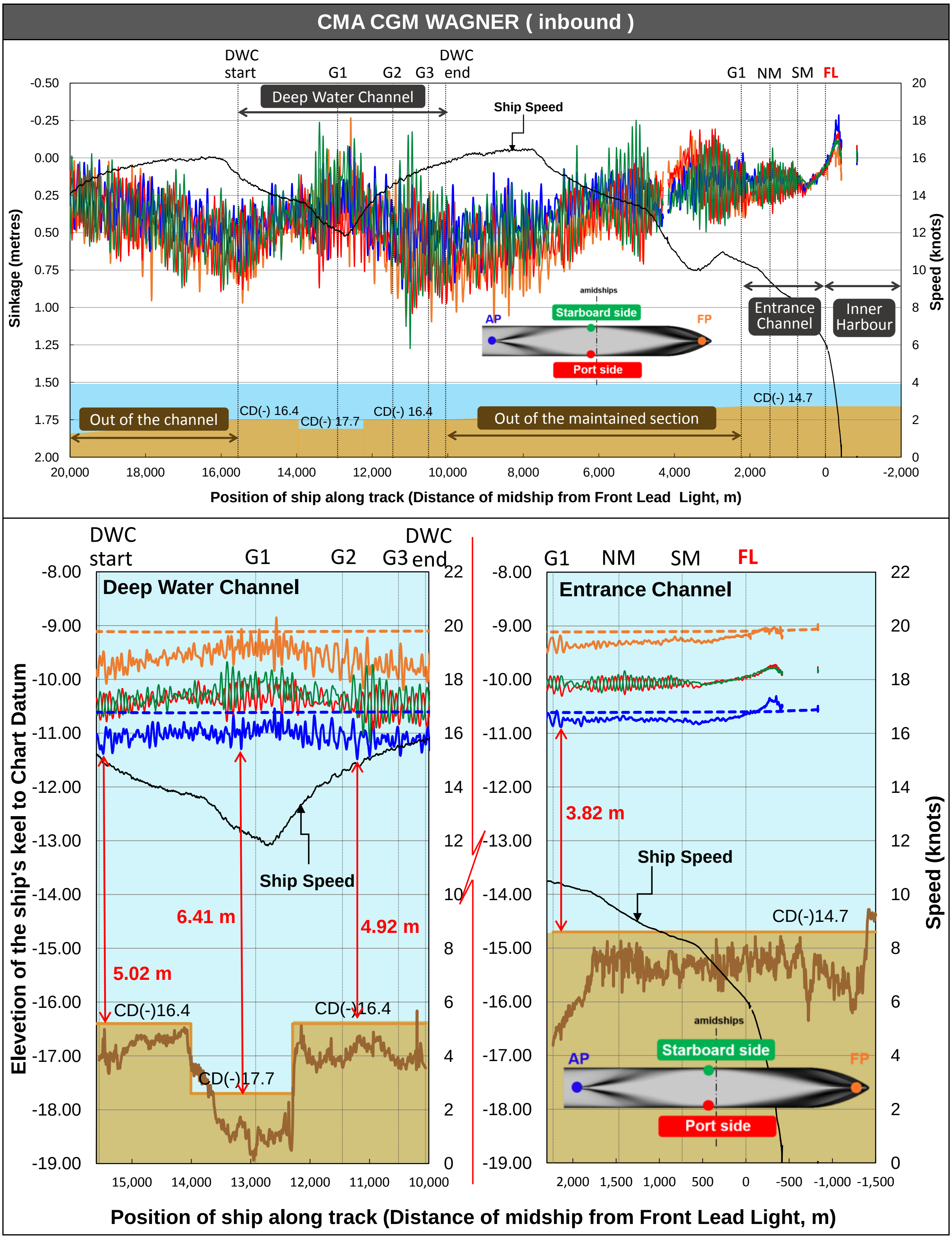
MOL PARAMOUNT (inbound)



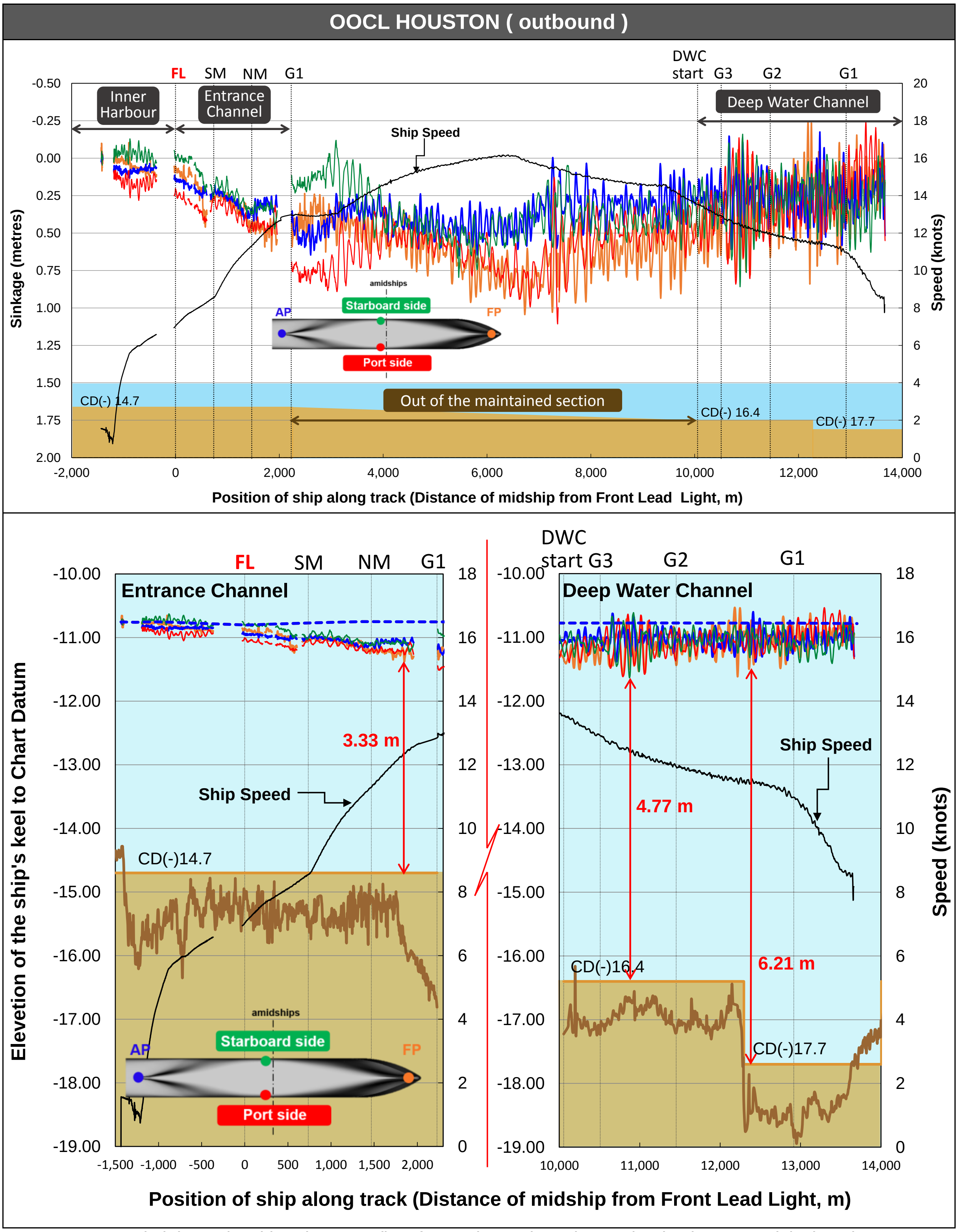
<Top> Measured sinkage (positive downward) at four points. Chart datum depths (not to scale) also shown. **<Bottom>** Elevation of the ship's keel relative to chart datum. Broken lines are elevations of the FP and AP including changes in tide only, i.e. their static position, not including squat and wave-induced motions. A flat seabed line is based on the charted depth on AUS112, and a fluctuating seabed line is the actual survey line provided by Fremantle Ports.



<Top> Measured sinkage (positive downward) at four points. Chart datum depths (not to scale) also shown.
<Bottom> Elevation of the ship's keel relative to chart datum. Broken lines are elevations of the FP and AP including changes in tide only, i.e. their static position, not including squat and wave-induced motions. A flat seabed line is based on the charted depth on AUS112, and a fluctuating seabed line is the actual survey line provided by Fremantle Ports.



<Top> Measured sinkage (positive downward) at four points. Chart datum depths (not to scale) also shown.
<Bottom> Elevation of the ship's keel relative to chart datum. Broken lines are elevations of the FP and AP including changes in tide only, i.e. their static position, not including squat and wave-induced motions. A flat seabed line is based on the charted depth on AUS112, and a fluctuating seabed line is the actual survey line provided by Fremantle Ports.



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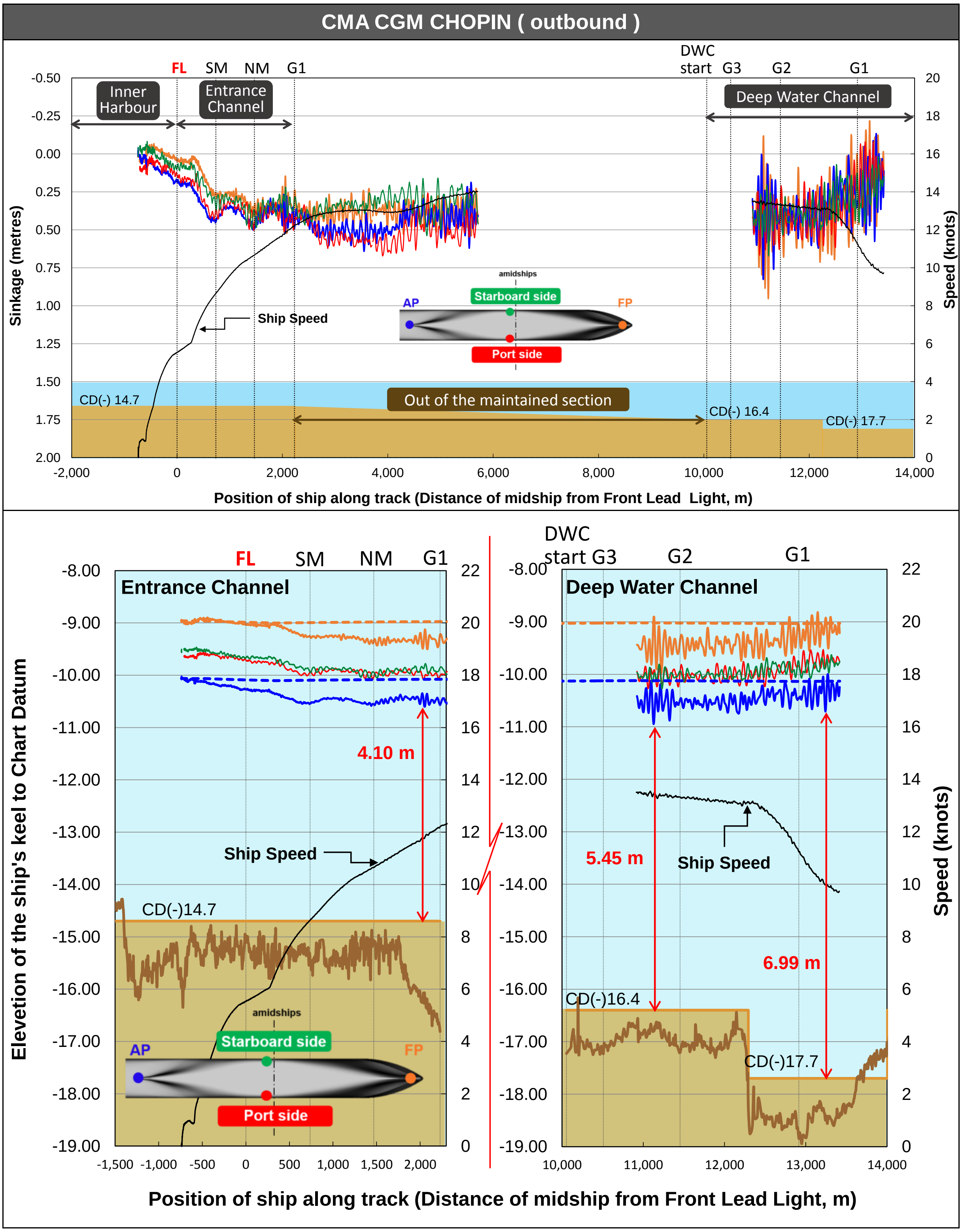

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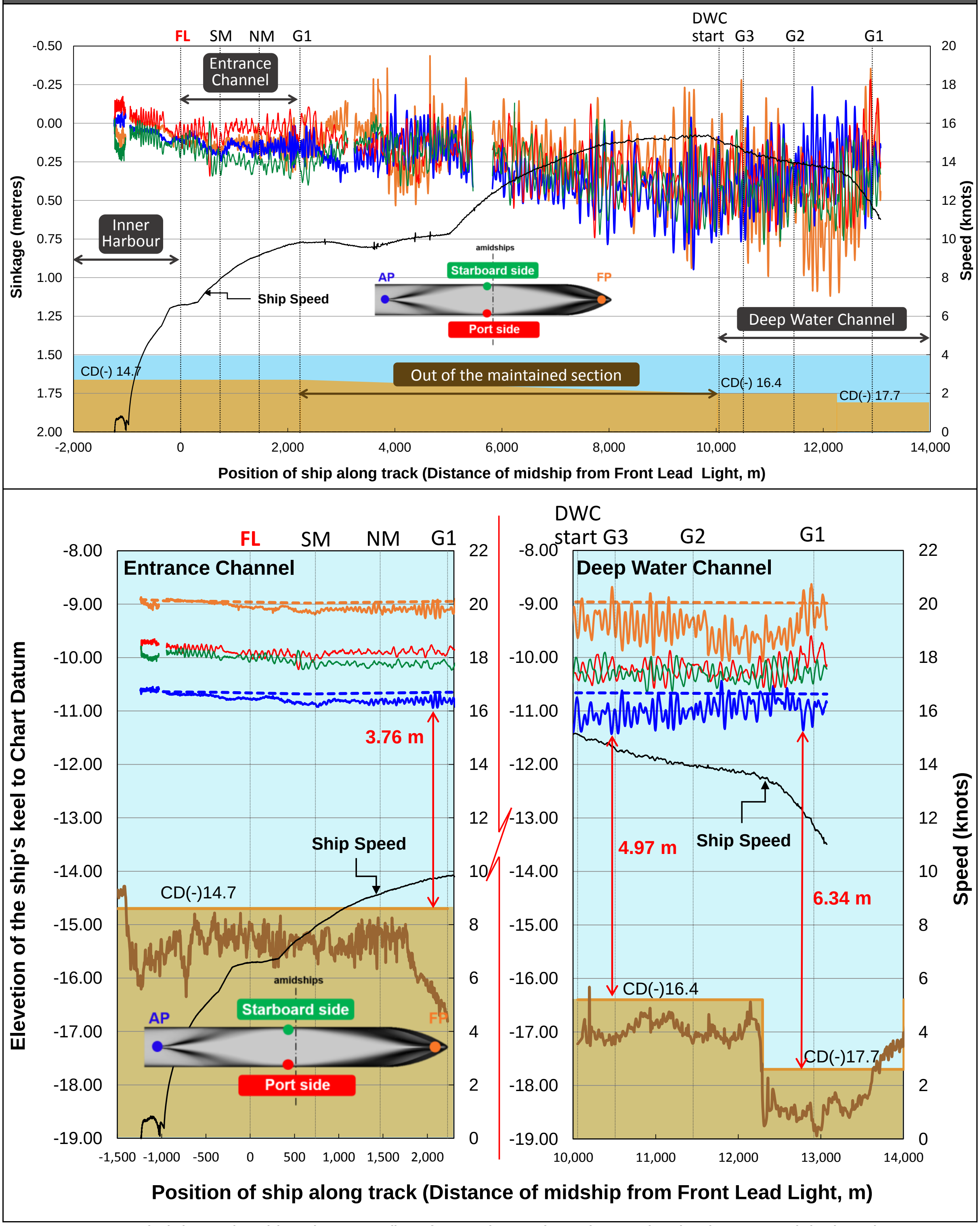
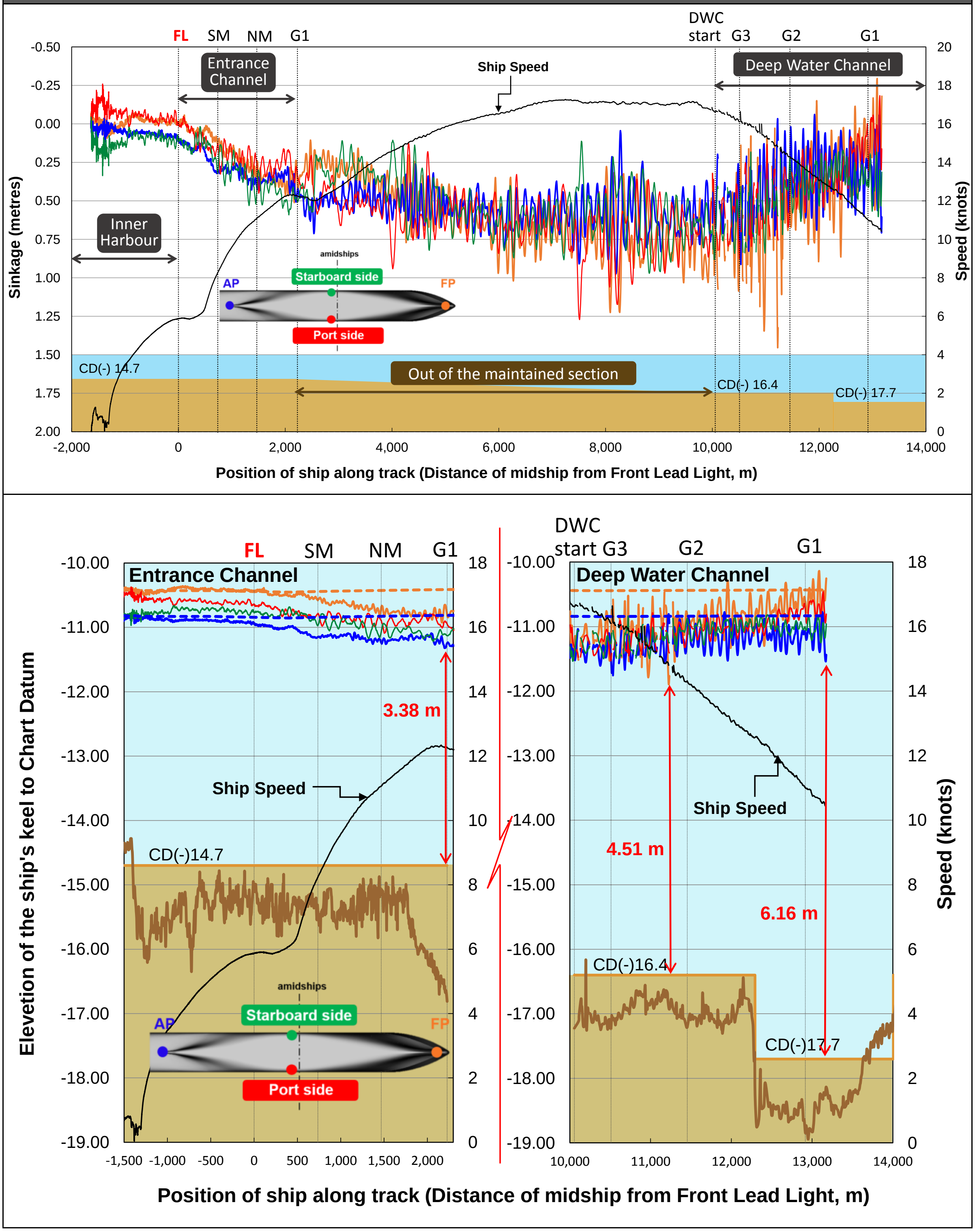
MOL EMISSARY (outbound)

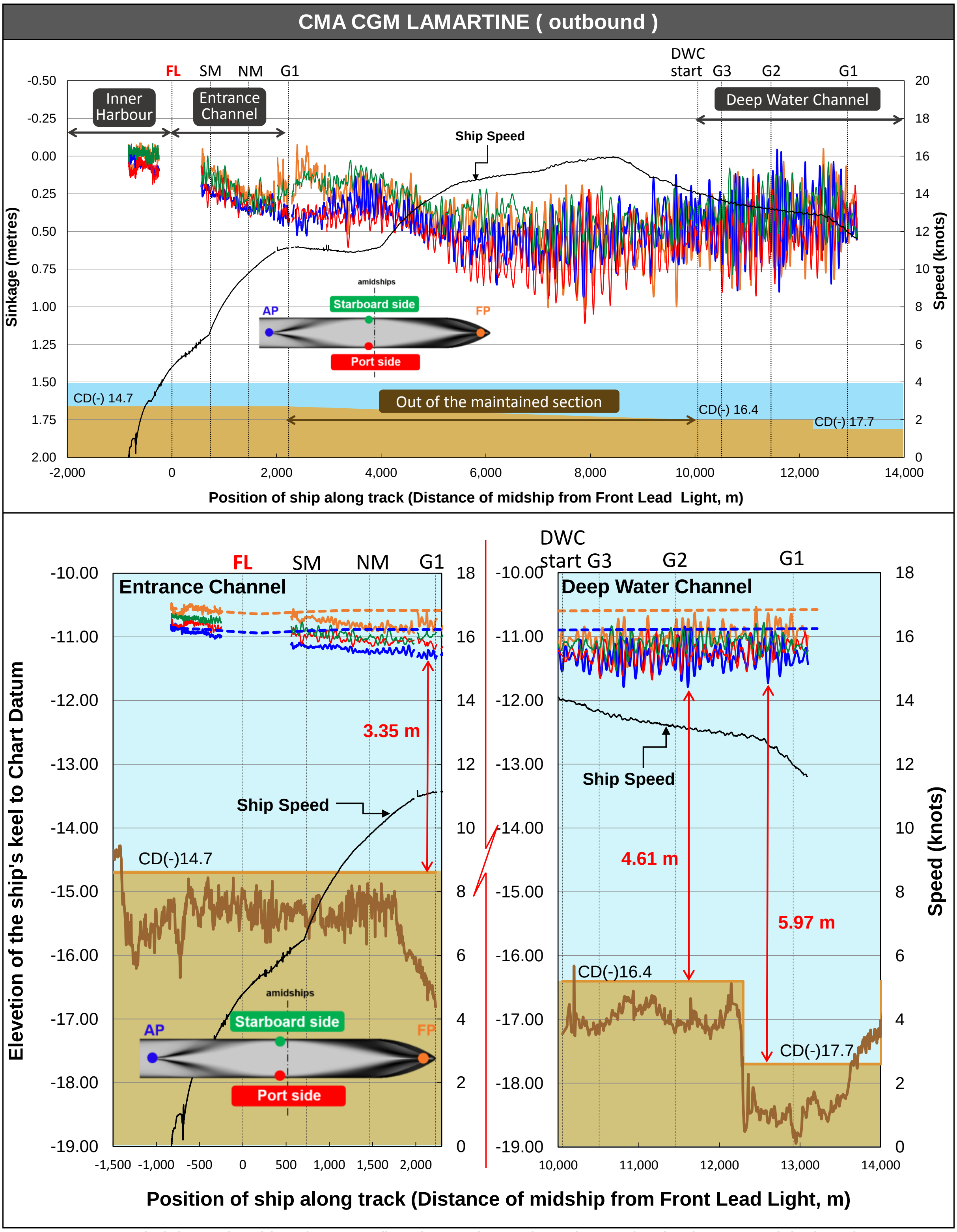


<Top> Measured sinkage (positive downward) at four points. Chart datum depths (not to scale) also shown.
<Bottom> Elevation of the ship's keel relative to chart datum. Broken lines are elevations of the FP and AP including changes in tide only, i.e. their static position, not including squat and wave-induced motions. A flat seabed line is based on the charted depth on AUS112, and a fluctuating seabed line is the actual survey line provided by Fremantle Ports.

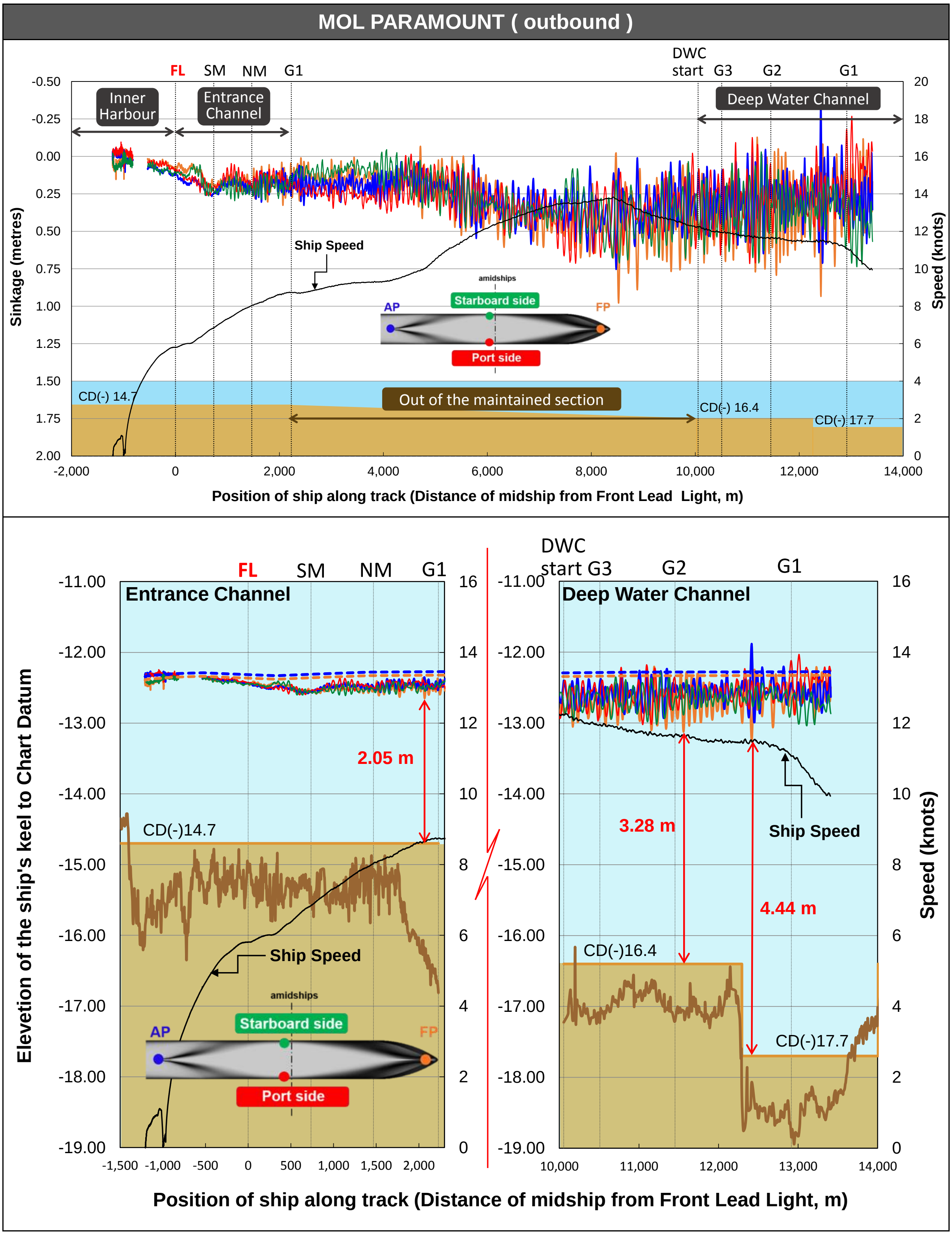
SAFMARINE MAKUTU (outbound)



<Top> Measured sinkage (positive downward) at four points. Chart datum depths (not to scale) also shown.
<Bottom> Elevation of the ship's keel relative to chart datum. Broken lines are elevations of the FP and AP including changes in tide only, i.e. their static position, not including squat and wave-induced motions. A flat seabed line is based on the charted depth on AUS112, and a fluctuating seabed line is the actual survey line provided by Fremantle Ports.



<Top> Measured sinkage (positive downward) at four points. Chart datum depths (not to scale) also shown. **<Bottom>** Elevation of the ship's keel relative to chart datum. Broken lines are elevations of the FP and AP including changes in tide only, i.e. their static position, not including squat and wave-induced motions. A flat seabed line is based on the charted depth on AUS112, and a fluctuating seabed line is the actual survey line provided by Fremantle Ports.



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