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ASTILLEROS BALENCIAGA S.A.

FAILURE MODES AND EFFECTS ANALYSIS
OF DIVING SUPPORT VESSEL
ADAMS CHALLENGE

Report No: GM 45214-0508-49138

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SUMMARY

This FMEA was compiled using documentation supplied from the ship builders and their subcontractors.

The vessel is to operate in DP Class 2 mode and it is intended to operate with the 690VAC bus tie closed. Providing the switchboard and breaker protection systems are functioning correctly whilst operating in this mode operating with closed main bus-tie is allowable.

The design worst case is the failure of one section of the 690V switchboard. This will fail one bow thruster and one after azimuth thruster and possibly the forward azimuth thruster. This is the accepted worst case scenario.

FMEA Proving Trials were undertaken between 20th and 27th February 2009 with a further visit to the vessel between 21st and 25th March, with the shipyard personnel and Owner's senior staff present. All Recommendations arising from these Trials have been subsequently closed-out.

On the basis of compliance with IMO/IMCA Guidelines and Recommendations, the vessel meets the requirements for Class 2 DP operations within the normal operational limits of the vessel.

1. INTRODUCTION

1.1 Instructions

1.1.1 Global Maritime received instructions from Snr. J.L. Sansinenea of Astilleros Balenciaga S.A. on 19th July 2007 to carry out the scope of work identified below, under Purchase Order No. 400/0035.

1.2 Scope of work

1.2.1 The scope of work consisted of:-

- To provide good advice to the Yard so that changes identified by the FMEA process are made early.
- Carry out analysis when enough information is available to produce a preliminary report.
- Write a test program to be included in the sea trials to prove the FMEA.
- Attend the FMEA part of the sea trials and record results.
- Produce a trials report.
- Finalise FMEA, (including tabulations of all critical and major failure modes) and trials report and issue for comment.
- Amend the report with valid client comments.

1.3 Objective

1.3.1 The objective of the FMEA is to identify the worst case failures and their effects on the position keeping performance of the vessel. Based on this, recommendations will be made to improve the performance or the safety of the vessel.

1.3.2 The study is carried out under the guidance of IMO 1994 Guidelines for Vessels with Dynamic Positioning Systems (ref: IMO MSC645 – June 1994).

1.4 Vessel Particulars

1.4.1 The Adams Challenge is a dynamically positioned multi-role offshore support vessel constructed at Astilleros Balenciaga S.A., Santiago Auzoa No.1, 20750 Zumaia, Spain, to be delivered in December 2008. The vessel has the following principal details:-

Length Overall (LOA):	85.74m
Length between Perpendiculars (LBP):	78.0m
Breadth, moulded:	18.0m
Depth, moulded:	8.0m
Design Draft:	5.75m
IMO No.	9407249

1.4.2 The vessel is classed by American Bureau of Shipping (ABS): Class ✠A1, circle E, ✠AMS, ✠DPS-2.

1.4.3 The vessel is fitted with a power generation system consisting of four Wärtsilä 8L26 diesel generator engines each of 2600kW.

1.4.4 Each generator drives an Indar BZK 710V/B9 marine alternator rated at 2495kW and supplies the 690VAC switchboard.

1.4.5 Propulsion is provided by twin azimuth thrusters aft, one retractable azimuth thruster forward, and two tunnel bow thrusters, all driven by frequency converter drives supplied from the 690VAC switchboard.

1.4.6 The generators are equipped with a dual redundant Power Management System. This is arranged to start the stand-by engine(s) when the total load reaches a preset high level and to shut down the stand-by engine(s) when the load is at the preset low level. However this shut down function will depend on minimum number of generators selected in PMS for each mode. For DP 2 operations it is envisaged that the vessel will operate with the main bus tie in the closed position, thus relying on the safety characteristics of the bus tie and system to ensure that a blackout situation will not be allowed to occur.

1.4.7 The DP System is a Kongsberg Maritime K-Pos dual redundant system. The vessel's DP reference systems consist of two Differential Global Positioning Systems, two Hydro Acoustic Reference systems, one Fan-beam laser and two Light Weight Taut Wires.

2. GLOSSARY OF TERMS

ABS	American Bureau of Shipping
BT	Bow Thruster
DB	Distribution Board
DG	Diesel Generator
DGPS	Differential Global Positioning System
DP	Dynamic Positioning
ECR	Engine Control Room
EDG	Emergency Diesel Generator
ESB	Emergency Switchboard
FC	Frequency Converter
FCV	Flow Control valve
FMEA	Failure Mode and Effect Analysis
FO	Fuel Oil
FW	Fresh Water
HP	High Pressure
HT	High Temperature
HTFW	High Temperature Fresh Water
IMO	International Maritime Organization
LO	Lubrication Oil
LPP	Low Power Distribution Board
LT	Low Temperature
LTFW	Low Temperature Fresh Water
LWTW	Light Weight Taut Wire
MDO	Marine Diesel Oil
MRU	Motion Response Unit
MSWB	Main Switchboard
OS	Operator Station
PLC	Programmable Logic Controller
PMS	Power Management System
PS	Port
QCV	Quick Closing Valve
SG	Shaft Generator
SB	Starboard
SW	Sea Water
SWBD	Switchboard
TCV	Thermostatic Control Valve
UPS	Uninterrupted Power Supply
VFD	Variable Frequency Drive

3. POWER GENERATION

3.1 General Description

3.1.1 The vessel has a total of four diesel generators for operational use. These supply 690V AC to the main switchboard.

3.2 Diesel Generators

3.2.1 The Wärtsilä 8L26 main generators are located side by side in a common engine room. Each main generator is of 8-cylinder type arranged in an inline configuration, equipped with a turbocharger situated at the free end of the engine. Each generator has an output of 2600 kW at 900 rpm and directly drives an Indar BZK 710V/B9 alternator, rated at 2495kW.

3.2.2 A Centamax flexible coupling is fitted between each generator and alternator.

3.2.3 All the main generators are designed for manual starting locally on the engine, remote starting from the ECR or automatic starting and stopping by the Power Management System. The engines can be emergency stopped locally or remotely from the ECR.

3.2.4 Starting of the main generators is performed using air supply from the start air system. Both start air compressors and receivers are located in the same engine room and presently configured in such a way that all DGs take air from the receivers via a common manifold. The engine shutdown cylinders also require 30 bar compressed air to shut off each individual HP fuel pump, and this is also taken from the start air common manifold. A solenoid must be energised to admit air to the shutdown cylinders on the engine.

3.2.5 In the event of a complete blackout situation or main switchboard bus failure, the Emergency Generator will supply power to the back up supply for all the engine pre-lubrication pumps and also Main Air Compressor No. 2.

3.2.6 The main generator engines are each equipped with direct-driven LTFW, HTFW, FO and LO pumps.

3.2.7 The automatic shutdown of a main generator will be activated by any of the following conditions:-

- Fresh Water High High Temperature.
- Over speed.
- LO Low Low Pressure.
- Major Governor failure.
- Failure of both RPM Pickups.
- Oil Mist Detector

3.2.8 The main generators are alarmed by activation of any of the following conditions:-

- Fresh Water High Temperature/Low Pressure.
- Fuel Oil Low Pressure.

- High Oil Mist Concentration in crankcase.
- LO Low Pressure/Low Sump Level/High Temp.
- LO Filter Pressure Differential.
- Cylinder 1 to 8 High Exhaust Temperature.
- Start Air Low Pressure.
- Failure of one RPM Pickup.
- Main Generator Control Power Failure.
- Deviation on ME Exhaust Temperatures.
- Charge Air Temperature.
- Pressure Leakage HP Fuel Pipes.
- LTFW High Temperature/Low Pressure.
- HT Cooling System Low Pressure.

3.2.9 Apart from these specific conditions above, the generator breaker is designed to disconnect in the event of:

- Short Circuit.
- Over Current.
- AVR Failure.
- Under Voltage.
- Over Voltage.
- Reverse Power.
- Under Frequency.
- Over Frequency.

3.2.10 Each alternator is supplied with an air cooler which is cooled from the LTFW system.

3.2.11 Engine-room ventilation is supplied from two supply fans, each one having sufficient capacity to supply all generators at full power. Each fan is supplied from either side of the 440VAC switchboard.

3.3 Diesel Generator Failure Modes

3.3.1 Mechanical failure due to major engine components will result in the shut down of the affected engine. As the load on each engine should not exceed 50% during DP 2 operations, the shutting down of one engine should not adversely affect the station keeping of the vessel. In the event of an engine shut down, the protection relay on the MSB will automatically disconnect non-essential services. If generator loads reach and or exceed 90% the PMS system will then disconnect non-essential services in 2 stages and shed propulsion load as required until the situation stabilizes.

3.3.2 In the event of the engine-driven fuel pump failing, the pump bypass can be opened and fuel is supplied to the engine by gravity, and the engine should continue to run.

3.3.3 Starting air supply failure will result in the engines continuing to run, but without any shutdown functions in operation.

3.3.4 Failure of one ventilation fan due to switchboard or mechanical failure will have no effect on generator load capacity as each fan is fully redundant.

3.4 Diesel Generator Failure Modes

3.4.1 Diesel Generator failure modes

Failure Mode	Cause(s)	Probability	Local Effect	Final Effect	Criticality	Remarks
Mechanical failure of one Generator.	Failure of major engine components.	Low	Loss of one engine.	Kongsberg system will reduce load on the running thrusters as necessary. PMS would cut in if online generator loads exceed 90%.	Major	Phase back of thrusters and DP power chop will occur.
Automatic engine shutdown.	Engine shutdown parameters met.	Low	Loss of one engine.	Kongsberg system will reduce load on the running thrusters as necessary. Switchboard preferential trips will operate. PMS would cut in if online generator loads exceed 90%.	Major	Phase back of thrusters and DP power chop will occur.
Flexible Coupling.	Failure of the rubber elements due to excessive vibration, oil contamination or old age.	Low	Loss of one engine.	Kongsberg system will reduce load on the running thrusters as necessary. Switchboard preferential trips will operate. PMS would cut in if online generator loads exceed 90%.	Major	Phase back of thrusters and DP power chop will occur.
Ventilation failure.	Switchboard or mechanical failure.	Low	Reduction in engine-room air supply.	Other fan has sufficient capacity to supply all generators.	Minor	

3.5 Diesel Generator Control

3.5.1 Each DG has a hydraulically operated centrifugal actuator which is controlled by a Woodward 723 governor.

3.5.2 Load sharing is achieved by the electronic speed governor and actuator. The speed governors communicate through load sharing lines and normally the generators connected to the switchboard will operate in isochronous mode.

3.5.3 A signal failure from the electronic governor to the hydraulic actuator will result in the generator shut down.

3.5.4 A signal failure on the load sharing line to any one generator, when the generators are in isochronous mode, could result in the generator acting out of synch with other generators online and could either hog or shed load depending on circumstances. The PMS is set up to provide a load sharing difference alarm at 5% and open bus tie if load sharing difference exceeds 25%. The operator can opt to choose droop mode for all online genes, upon PMS imbalance alarm, through the switch provided on the MSB and balance the generators manually. In the event the bus-tie is opened by PMS or manually, to reinstate it the operator may require to deselect the imbalance monitoring function temporarily from PMS until the bus-tie is closed.

3.5.5 In the event of a complete failure of the PMS the MSB will revert to droop mode. Switchboard load can then be balanced manually

3.5.6 Each generator is controlled by the engine mounted ESM, the electronic speed governor and the PLC based Stop/Start system.

3.5.7 The generators each have two speed pickups for the electronic governors, which have a fixed speed mode of 900rpm and over-speed protection.

3.5.8 Two other separate speed pick ups supply the ESM to shut down the generators in the event of over-speed. The first is set to 115% of engine speed (1035rpm) and the second at 118% (1062rpm).

3.5.9 The PMS is designed to protect the engines from overload. It continuously monitors the engine load and reduces the propulsion load automatically if the total load should exceed a pre-set load limit prior to the automatic starting and synchronizing of a stand-by generator.

3.6 Control Failure Modes

3.6.1 Should the PMS fail, the generators will share the load in droop mode. The operator will need to balance the generators manually if any imbalances are present.

3.6.2 In DP at 900 rpm the feedback signal from both speed pick ups is used to keep the rpm constant. The failure of one speed pick up causes a minor governor alarm; failure of the second causes the engine to shut down with a major governor alarm. Failure is considered to be loss of signal. If there is a difference between the two sensors, the faster signal is used and an alarm is given.

3.6.3 Mechanical failure of an actuator will result in the loss of an engine.

3.6.4 A major failure of the WW723 regulator will cause an engine shutdown.

3.6.5 Over or under excitation caused by an AVR failure will cause the generator to trip off from the switchboard.

3.6.6 Bus bar instability could occur if AVRs are not set up correctly.

3.7 Diesel Generator Control Failure Modes

3.7.1 Diesel Generator Control failure modes

Failure Mode	Cause(s)	Probability	Local Effect	Final Effect	Criticality	Remarks
Mechanical failure of actuator.	Failure of bearings or drive shaft breakage.	Low	Loss of generator.	Vessel maintains position with reduced capability. Switchboard preferentials and PMS may cut in if online generator loads exceed 90%.	Major	Phase back of thrusters and DP power chop will occur. Bus tie may open if load imbalance exceeds 25% between generators.
Fuel rack control failure.	Mechanical or electrical failure.	Low	Load control disabled on affected engine.	Could cause instability of switchboard and may require manual intervention by watch-keeper.	Minor	Load imbalance could occur and generator may need to be isolated. Bus tie may open if load imbalance exceeds 25% between generators.
Failure of one governor Speed Signal.	Electrical failure.	Low	Minor Governor Alarm in ECR.	No propulsion loss.	Minor	Loss of both speed sensors will cause a major governor alarm and engine shut down.
Failure of 723 Governor.	Internal or power supply failure.	Low	Loss of generator.	Vessel maintains position with reduced capability. Switchboard preferentials and PMS may cut in if online generator loads exceed 90%.	Major	Phase back of thrusters and DP power chop will occur. Bus tie may open if load imbalance exceeds 25% between generators.
Loss of power supply to Engine Control System (UNIC C1).	Electrical failure.	Low	Alarm in ECR and loss of main engine shutdown functions.	No propulsion loss.	Minor	Provided with a back up 24V supply.
AVR Failure.	Loss of supply Short circuit Open circuit PMG failure	Low	Over Excitation Under Excitation	Loss of affected generator Switchboard preferentials and PMS may cut in if online generator loads exceed 90%.	Major	Phase back of thrusters and DP power chop will occur. Bus tie may open if load imbalance exceeds 25% between generators.

3.7.1 Diesel Generator Control failure modes (continued)

Failure Mode	Cause(s)	Probability	Local Effect	Final Effect	Criticality	Remarks
Over-speed of generator.	Mechanical failure of fuel actuator Fuel actuator failure Fuel control linkage seizure.	Low	Loss of generator.	Loss of affected generator Switchboard preferentials and PMS may cut in if online generator loads exceed 90%..	Major	Phase back of thrusters and DP power chop will occur. Bus tie may open if load imbalance exceeds 25% between generators.
Loss of kW signal to PMS.	Wire break / sensor failure.	Low	Generator tripped by PMS.	Loss of affected generator. Switchboard preferentials and PMS may cut in if online generator loads exceed 90%.	Major	Phase back of thrusters and DP power chop will occur.
Loss of kW signal in non PMS mode.	Load sharing circuit failure.	Low	Generator continues to run.	No propulsion loss.	Minor	DP spinning reserves affected.

3.8 Harbour Generator

3.8.1 A 500KW Volvo Penta harbour generator is fitted with a Stamford alternator and can supply the 690V switchboard.

3.8.2 The harbour generator uses 30bar compressed air for starting.

3.8.3 The harbour generator can only be paralleled to one main DG whilst transferring the shipboard load to it, which must be less than the harbour generator's capacity.

3.8.4 The harbour generator is not considered to be part of the DP system of the vessel and so will not be considered further.

3.9 Emergency Generator

3.9.1 A 440V, 60Hz, 450kW Volvo Penta emergency generator set is installed. It is a stand alone engine complete with a dedicated fuel tank. This generator has two independent sets of starter batteries and charger and will start up automatically in the event of a blackout of the 440V bus bar.

3.9.2 The emergency generator has the following warning alarms:

- High LO temperature
- Low LO pressure
- Fresh Water cooling high temperature
- Fresh water low pressure
- Low cooling water level.

3.10 Emergency Generator Failure Modes

3.10.1 The generator will only shut down in the event of a major mechanical failure or over speed.

3.10.2 The emergency generator is not considered to be part of the DP system of the vessel and so will not be considered further in this analysis.

4. FUEL OIL SYSTEM

4.1 Diesel Generator Fuel Oil System

4.1.1 The fuel oil system is illustrated in Figure 4-1 on the following page:-

4.1.2 The vessel is equipped with two daily service tanks with a capacity of 44 m^3 and $47m^3$. The fuel is transferred from the settling tank to the service tanks, via quick closing valves (QCV), through a filter to the purifier feed pump. This supplies FO through the air operated flow control valve (FCV), to the purifier (with a maximum throughput of $3.9m^3/h$). The level in the daily service tanks is monitored by the watch-keeper, who controls the purifier throughput manually as necessary, and these tanks are fitted with both high and low level alarm sensors. Above the high level sensors are fitted overflow sight glasses which are also alarmed. This fuel overflow returns fuel to the respective settling tank. There is also another higher overflow line which flows to an Overflow Collector which returns fuel to the Overflow Tank. The levels of the settling tanks are maintained by transferring from other storage tanks by use of the FO transfer pumps. These Settling Tanks are fitted with high level alarms, and have a similar set of overflow arrangements to the Service Tanks, with both lines draining back to the Overflow Tank.

4.1.3 The engines are intended to run on MGO fuel only and the fuel supply to all generator engine driven pumps is by gravity feed alone.

4.1.4 Each pair of generators is supplied with fuel from their respective Service Tanks. The FO is supplied via a QCV located on each Day Tank and via a common line, through a "T" connection to duplex filters on each engine. The excess fuel returns to the Day Tank from each pair of engines into a common return line back to the respective tank. There is a cross-over valve between the two Service Tanks that allows fuel to be fed to both engines from one Day Tank, although this will normally remain closed.

4.1.5 The Quick Closing Valve cabinet is situated on the main deck, outside of the accommodation at Fr.75.

4.1.6 The electrical supplies are arranged as follows:-

FO purifier1	440V PS bus-bar
FO purifier2	440V SB bus-bar
FO transfer pump 1	440V PS bus-bar
FO transfer pump 2	440V SB bus-bar

4.2 Fuel System Failure Modes

4.2.1 In the event of an engine-room fire all QCVs will be closed, resulting in the loss of all propulsion. All high pressure fuel lines are double skinned and alarmed for leakage, thus reducing the risk of any fuel spray igniting.

4.2.2 Should an engine-driven pump fail it can be bypassed and the engine will continue to operate on gravity feed from the Service tanks.

4.2.3 Fuel contamination can cause serious problems. Water contamination can result in erratic running or possibly the loss of the engines supplied by that service tank. Other contaminants will be filtered out prior to the fuel pump. These filters are a duplex arrangement and adequately alarmed for differential pressure across them, so can be easily changed over and cleaned.

4.2.4 Failure of a fuel purifier should be of minor consequence as there are two purifiers and a back up using the fuel oil transfer pumps in an emergency situation.

4.2.5 Accidental activation of the QCVs is not directly alarmed, but it will quickly be seen from FO low pressure alarms at the generators.

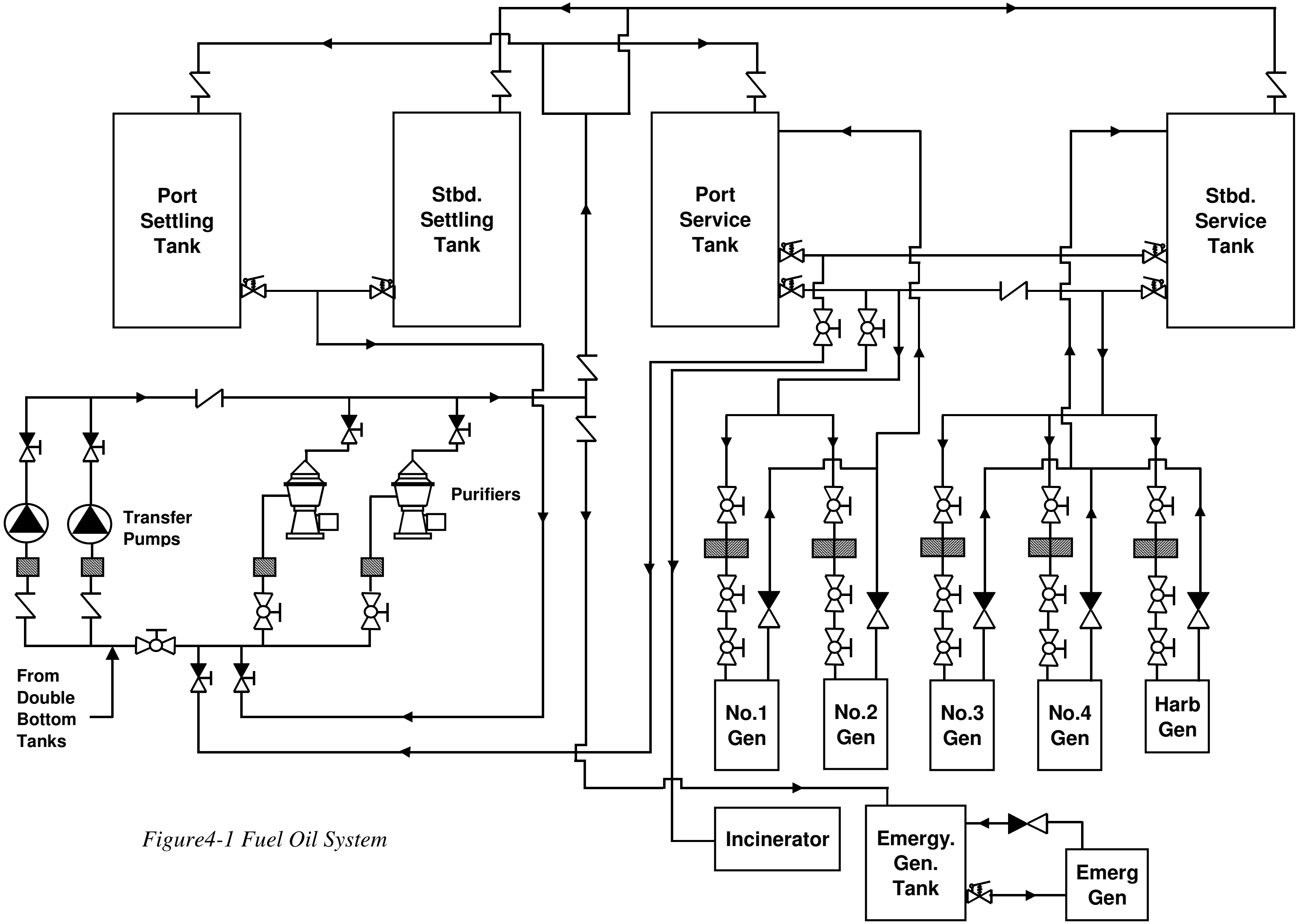


Figure4-1 Fuel Oil System

4.3 Diesel Generator Fuel Oil System Failure Modes

4.3.1 Diesel Generator Fuel Oil System Failure Modes

Failure Mode	Cause(s)	Probability	Local Effect	Final Effect	Criticality	Remarks
Fuel oil supply.	Line fracture.	Low	Low pressure alarm in ECR, standby pump starts.	Loss of main engine, thruster(s) if problem not resolved quickly.	Medium	Vessel maintains position with reduced capability.
	Filter blockage.	Low	Filter high differential Alarm in ECR.	Change over supply to clean filter.	Minor	No loss of position.
	Contamination.	Low			Minor	Source of contamination to be located and fuel and tanks to be treated accordingly. No loss of position.
	Water contamination.	Low	Sudden loss of power to affected engines.	Loss of generators connected to the affected tank and thrusters if problem not resolved quickly.	Medium	Mitigated by good watch keeping practices. Cross-over valves fitted to supply fuel from other Day tank. Vessel maintains position with reduced capability.
	Accidental activation of one QCV.	Low	FO Low pressure alarm.	Loss of generators and thrusters if problem not resolved quickly.	Medium	Vessel maintains position with reduced capability

4.4 Harbour Generator Fuel Oil System

4.4.1 The Harbour Generator is supplied from the Port Service tank, via the same QCV and supply line as for the Port Generators. Prior to the engine is a set of duplex filters and the return fuel line connects in with the return line from the Port Generators.

4.5 Harbour Generator Fuel Oil System Failure Modes

4.5.1 The Harbour Generator is under the same failure conditions as the main and auxiliary engine fuel oil failures. Any failure will only affect the Harbour Generator and will not affect DP station keeping.

4.6 Emergency Generator Fuel Oil System

4.6.1 The Emergency Generator is supplied from the Emergency Generator fuel tank, which is filled from the purifier discharge line as required. This tank has High and Low Level alarm sensors.

4.6.2 The overflow line from the Emergency Generator fuel tank is led to the Starboard Service Tank.

4.6.3 Fuel is supplied to the Emergency Generator via a QCV and returns to the same tank.

5. COOLING WATER SYSTEMS

5.1 Seawater Cooling System

5.1.1 The main SW cooling system is split into port and starboard sections each with its dedicated SW pump, and a common standby pump which can be configured to supply either system as required.

5.1.2 The system consists of two sea chests, two suction filters (strainers) supplying a common forward suction manifold. Each system is supplied by a single speed main SW pump and a standby SW pump can be configured to supply either system as required, all have the same capacity of 600m^3/h at a pressure of 2 bar.

5.1.3 Each system provides coolant for their respective LTFW cooler. There is also provision made to be able to back flush the SW side of the coolers plates.

5.1.4 Each sea suction chest is fitted with an air vent to the main deck level, an inlet for chemical dosing and a compressed air line for weed blowing.

5.1.5 The pumps can only be started from the starting panel in the engine room.

5.1.6 The standby pump's valves are kept closed. In the event of a main pump failure a low pressure alarm in the ECR will alert the watch-keeper, who will configure the stand by pump to provide cooling to the required system. In the event of a blackout the pumps will require restarting manually on power being restored.

5.1.7 The electrical supplies to the pumps are arranged as follows:-

• No.1 SW cooling pump	440V PS bus-bar
• No.2 SW cooling pump	440V PS bus-bar
• No.3 SW cooling pump	440V SB bus-bar

5.1.8 The Port sea suction manifold supplies water to other consumers. These are Heli-deck pump No.1 and the Port Fresh Water Generator SW pump.

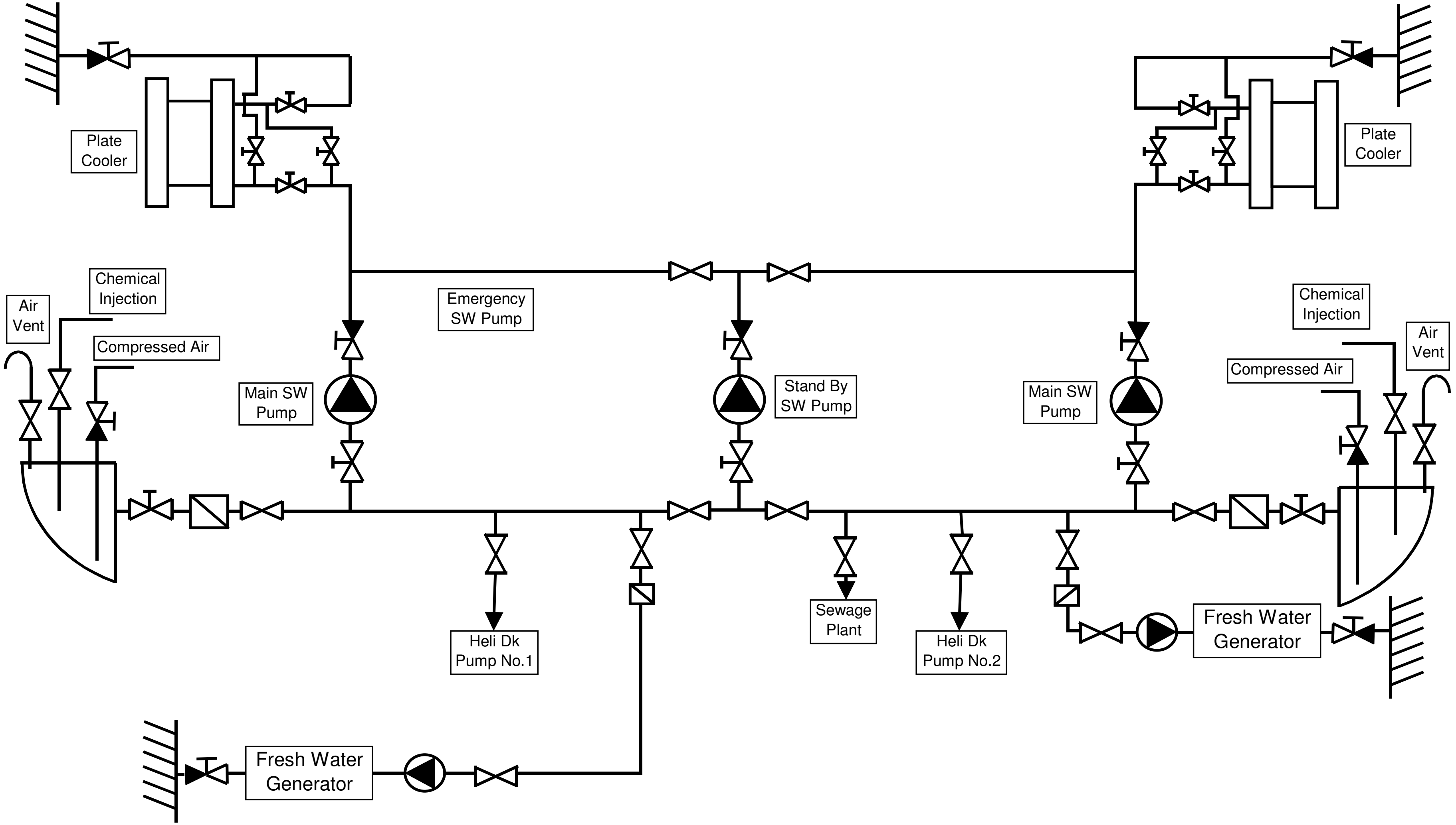
5.1.9 The Starboard sea suction manifold also supplies water to other consumers. These are Heli-deck pump No.2, the Starboard Fresh Water Generator SW pump and the Sewage system.

5.2 Seawater Cooling Failure Modes

5.2.1 Failure of a dedicated SW pump will result in a low system pressure alarm and the manual start of the standby pump.

5.2.2 The forward suction manifold is provided with two cross-over valves, so in the unlikely event of failure of a manifold section, it can be isolated and all cooling can be supplied from the remaining section by utilizing the standby pump.

5.3 Sea Water Cooling System Diagram



5.4 Seawater Cooling System Failure Modes

5.4.1 Seawater Cooling System Failure Modes

Failure Mode	Cause(s)	Probability	Local Effect	Final Effect	Criticality	Remarks
Sea Water Pressure.	Blocked suction filter.	Medium	Low pressure alarm in ECR. Standby pump starts.	Reduced cooling.	Minor	Quick action by ER staff will prevent this problem manifesting itself further.
	Pipe-work failure.	Low	Low pressure and high bilge alarms in ECR. Standby pump starts.	Reduced cooling could result in high engine cooling temperatures and engine shutdown.	Medium	Inform DPO if fault cannot be easily rectified. Engines will be operating on reduced load and there will be ample reserve capacity.
	Pump failure.	Low	Low pressure alarm in ECR. Standby pump configured and started by operator.	Cooling water pressure returned.	Minor	No loss of position.
LT Cooler.	Choked or dirty plates.	Low	Rise in LT temperature.	High LT temperature could result in high engine temperatures and engine shutdown.	Minor	Each system is fitted with a back-flushing arrangement. Planned maintenance of cooler will reduce likelihood of this occurring.

5.5 Fresh Water Cooling Systems

5.5.1 The LTFW system is split into port and starboard systems and circulation of these systems is maintained by dedicated FW pumps. There is also a standby pump provided which can be configured and manually started to provide coolant to either system as necessary. All three LTFW circulation pumps are identical and are rated at 442m^3/h at 4 bar.

5.5.2 The Port circulation system provides cooling specifically for the Port LT cooler, the Port Generators and alternator coolers, all coolers for Aft Thruster No.4 and Bow Thruster No.1, the A-Frame hydraulic oil cooler and the Tool Compressor cooler.

5.5.3 The Starboard circulation system provides cooling specifically for the Starboard LT cooler, the Starboard Generators and alternator coolers, all coolers for Aft Thruster No.5 and Bow Thruster No.2, the ECR air conditioning, the Control air dryer and the Harbour Generator.

5.5.4 Either system can be configured to supply LTFW to the Saturation Diving system coolers, the refrigeration compressors, the air conditioning compressors and all coolers relating to the Retractable Thruster.

5.5.5 The LTFW system provides primary coolant to each Frequency Converter cooling water system.

5.5.6 Each LT system is fitted with a 500 litre water expansion tank which is filled from the domestic fresh water system. Each expansion tank is equipped with a low level alarm and provision for the addition of anti-corrosion treatment.

5.5.7 Each generator is fitted with a direct driven LTFW pump which draws FW from the circulation system.

5.5.8 The LTFW is diverted through a AMOT wax-stat operated TCV regulating the temperature to the charge air cooler. From the charge air cooler the FW is diverted to the LO cooler and into a common return line to the main cooler.

5.5.9 Each generator has a dedicated HTFW system with a direct driven HTFW pump and a pre-heater complete with a small circulation pump.

5.5.10 The HTFW pump circulates the HTFW through the engine. When the FW temperature reaches a pre-set limit a thermostatically controlled diverter valve returns coolant to the pump suction or to the Fresh Water Generator system and then to the HT cooler.

5.5.11 There are two (one PS and one SB) Fresh Water Generators. Each FW Generator can be supplied with HTFW from either generator on its respective side, by means of mechanically linked supply and discharge valves.

5.5.12 Each generator HT system is fitted with a 500 litre water expansion tank which is filled from the domestic fresh water system. Each expansion tank is equipped with a low level alarm and provision for the addition of anti-corrosion treatment.

5.5.13 The electrical supplies for the LT pumps are arranged as follows:-

No.1 LT pump	440V PS bus-bar
No.2 LT pump	440V SB bus-bar
No.3 LT pump	440V SB bus-bar.

5.6 Freshwater Cooling Failure Modes

5.6.1 Failure of an engine-driven HT or LT pump will result in low pressure in the system and eventually engine shut down on high temperature.

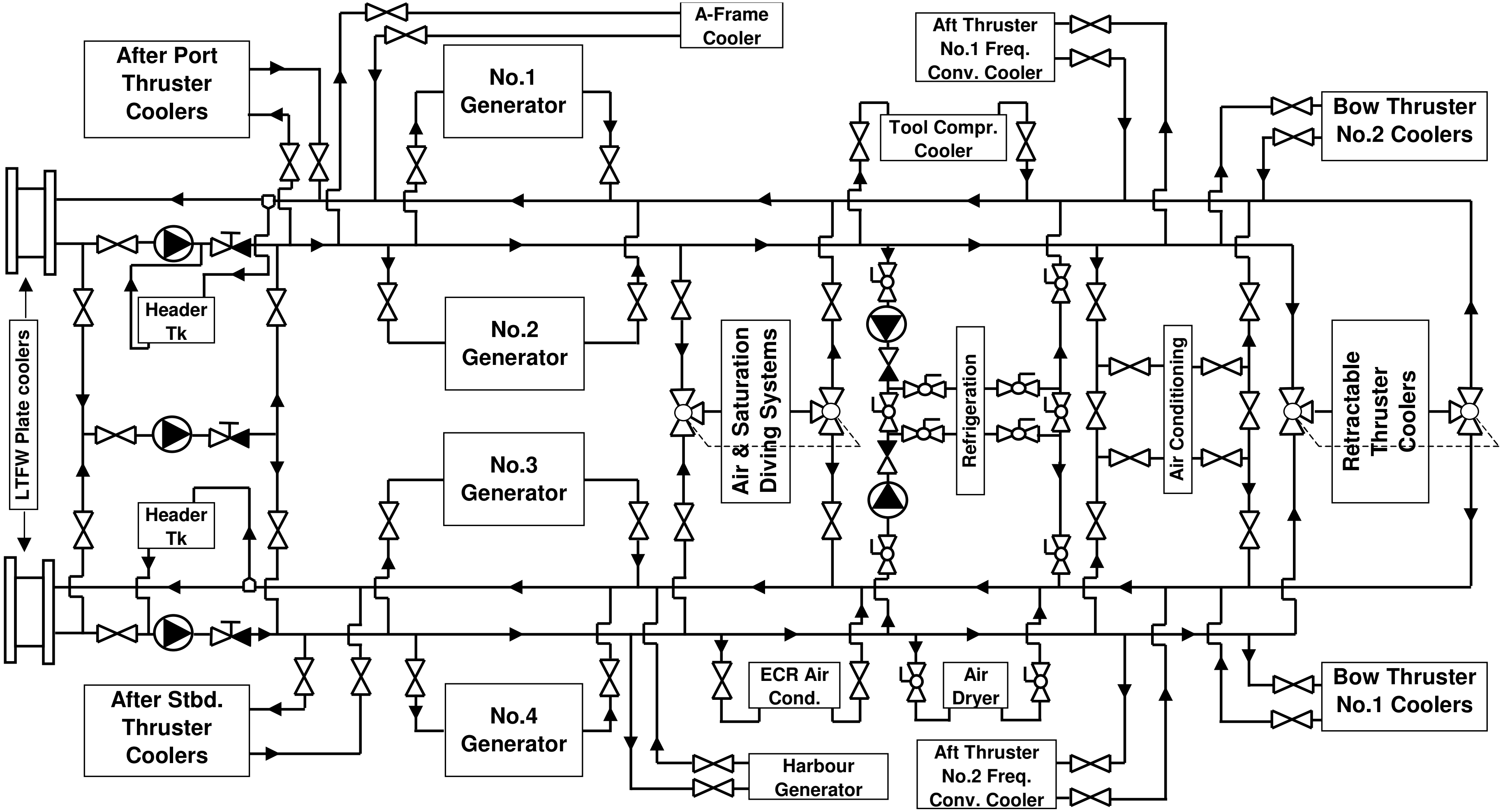
5.6.2 Small system leakages will eventually result in a low level alarm in the respective header tank. Each header tank can be refilled with water from the domestic system.

5.6.3 LTFW supply to the Frequency Converter cooling water heat exchangers will result in a gradual rise in temperature of these small systems and eventual loss of the FC altogether.

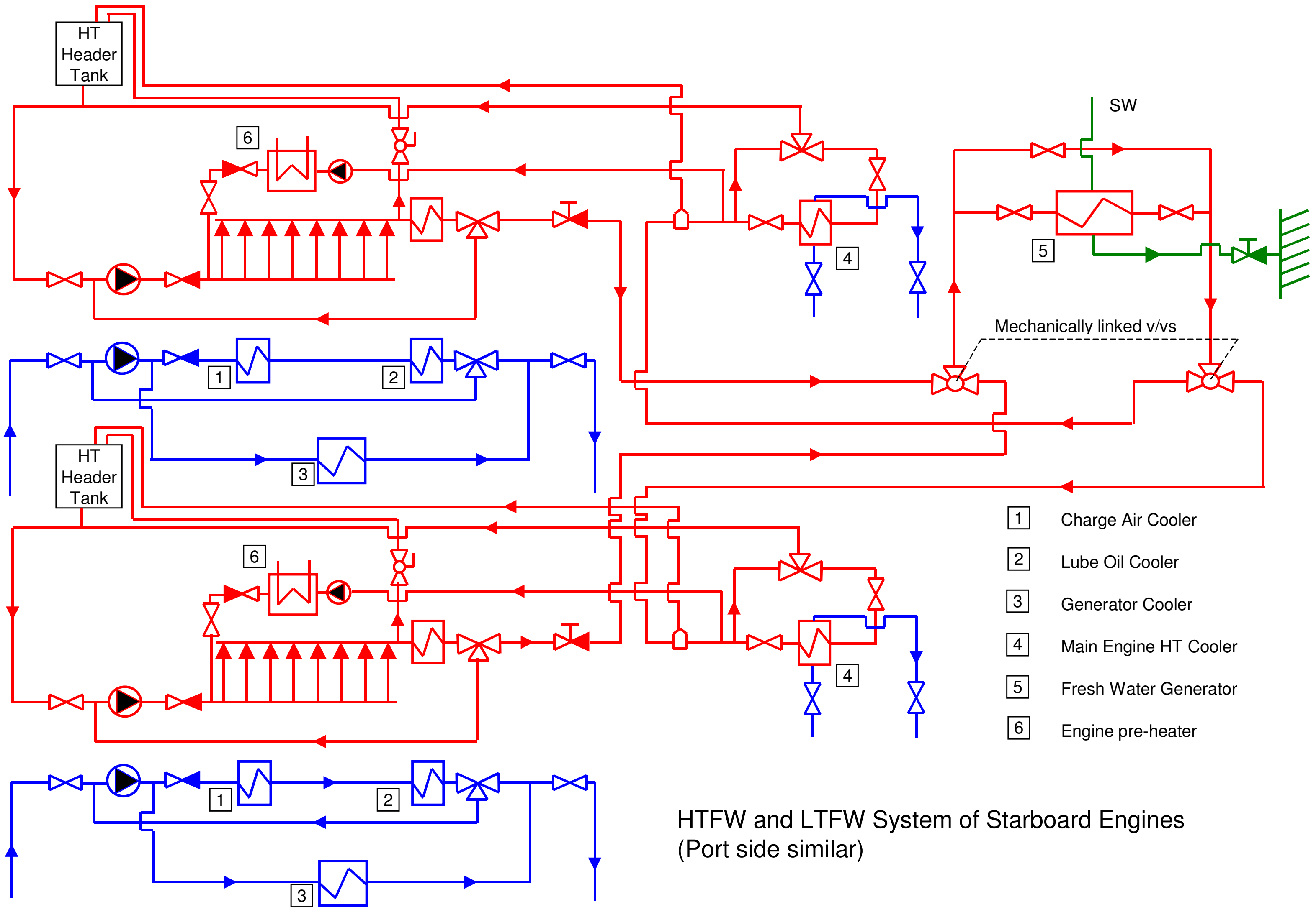
5.6.4 Major system leakages will result in a rapid coolant loss and the overheating and shut down of the affected engine only. In this instance the PMS should prevent a blackout situation.

5.6.5 Failure of the thermostatically operated water diverter valves will affect one engine only. These valves can be operated manually to maintain some control of the affected system.

5.7 General Arrangement of LTFW System



5.8 HTFW Cooling Arrangement for Generators



5.9 Fresh Water Cooling System Failure Modes

5.9.1 Fresh Water Cooling System Failure Modes

Failure Mode	Cause(s)	Probability	Local Effect	Final Effect	Criticality	Remarks
HTFW Pressure.	Engine driven pump failure.	Low	Low pressure alarm in ECR.	Loss of engine.	Minor	No effect on DP as engines will be operating on reduced load and there will be ample reserve capacity.
LTFW Pressure.		Low		Loss of engine.	Minor	No effect on DP as engines will be operating on reduced load and there will be ample reserve capacity.
LTFW Pressure	LTFW Circulation pump failure.	Low	Low pressure alarm in ECR.	FC temperature rise and ultimate shutdown.	Major	Standby pump will be required to be set up manually. Time of FC shut down will depend on thruster load.
LT Cooler.	Blocked cooler. TCVs not functioning.	Low	High Temperature alarm in ECR.	High LT temperature could result in high engine cooling temperatures and engine shutdown.	Major	Planned maintenance of cooler and checking of TCVs will reduce likelihood of this occurring.
Leakage.	Pipe failure.	Low	Bilge, header tank low level and high temperature alarms in ECR.	Could result in high engine temperatures and engine shutdown.	Minor	Inform DPO if fault cannot be easily rectified. Engines will be operating on reduced load and there will be ample reserve capacity.

5.10 Harbour Generator

5.10.1 The harbour generator is cooled by the main LTFW system.

5.10.2 This engine will have no impact on the DP capability of the vessel.

5.11 Emergency Generator Cooling Water System

5.11.1 The emergency generator has its own FW cooling system consisting of an engine driven cooling pump, an air fan and a radiator with expansion tank. The FW is cooled by means of a directly driven fan.

5.12 Emergency Generator Cooling Water System Failure Modes

5.12.1 Failure of this system will only result in the loss of the emergency generator, as a single failure it has no effect on DP station keeping.

6. LUBRICATION OIL SYSTEM

6.1 Diesel Generator Lubricating Oil System

6.1.1 Each main engine has its own LO system consisting of a LO sump equipped with a low-level sensor, an electrically driven pre-lubrication pump and a direct driven main LO pump.

6.1.2 Each engine has a pre-lubrication pump which is in operation constantly when the engine is stopped. These pre-lube pumps are dual supplied from either the starboard 440VAC switchboard or the Emergency 440VAC switchboard.

6.1.3 Purification of the main generators LO is effected by an engine mounted centrifugal filter and one Alfa Laval MMB-304 LO separator that can be configured for each generator engine separately. The LO is supplied from the main generator through a filter into the purifier feed pump, which diverts the LO to the electric pre-heater. Beyond the pre-heater, the LO passes through an air operated three way valve which diverts the LO through the LO purifier or straight into the discharge line returning to the engine sump.

6.1.4 The engine driven pump is provided with suction directly from the sump and it is discharged via a TCV through the LO cooler, which is LTFW cooled. The TCV controls the flow through the cooler and is set at a pre-set temperature. Temperature indicators are installed on both sides of the cooler. From the cooler the LO is diverted through the LO filters and then distributed to the several LO points on the engine. The LO system is alarmed for low level, low and extreme low LO pressure. The TCV is thermostatically controlled by AMOT wax-stats.

6.1.5 Replenishment of the sump tanks is achieved by gravity from a high mounted storage tank.

6.1.6 A pump is provided for changing engine oil, which can be configured for each engine separately, and this will pump the used oil directly to the Dirty Oil Tank.

6.1.7 The electrical supplies for the LO pumps are arranged as follows:-

• LO pre-heater separator	440V PS bus-bar
• LO separator	440V PS bus-bar

6.2 Lubricating Oil System Failure Modes

6.2.1 All failure modes of the lubricating oil system will affect one engine only.

6.2.2 Failure of the engine-driven pump will result in the shutdown of the engine. The PMS should prevent a blackout event.

6.2.3 Failure of the purifier can result in the loss of oil from the system. This will result in the gradual lowering of the sump level which will trigger a sump low level alarm.

6.3 Diesel Generator Lubricating Oil System Failure Modes

6.3.1 Diesel Generator Lubricating Oil System Failure Modes

Failure Mode	Cause(s)	Probability	Local Effect	Final Effect	Criticality	Remarks
L.O Purifier.	Failure in service.	Low	ECR Alarm and oil redirected back to sump.	No effect on running engine.	Minor	
	Pre-heater failure.	Low	ECR Alarm and oil redirected back to sump.	No effect on running engine.	Minor	
Engine driven LO pump.	Failure in service.	Low	Generator engine Low LO pressure alarm in ECR and engine failure.	Loss of generator.	Major	Watch-keeper should immediately ascertain the reason for the pump failure which could be low LO level.
Pre-lub pump failure	Electrical or mechanical failure	Low	Alarm for loss of auto-standby of engine.	Loss of generator.	Minor	Watch-keeper should immediately ascertain thereason for the pump failure. Should another generator shut down, then this will reduce station keeping ability.

6.4 Lubricating Oil System Harbour Generator

6.4.1 The Harbour Generator engine has its own LO system. The engine driven LO pump is provided with oil supply from the wet sump of the engine. From the sump it is pumped through the LO cooler and returns to the wet sump. There are low pressure and low low pressure alarms installed in the system.

6.5 Lubricating Oil System Harbour Generator Failure Modes

6.5.1 Any failure of the LO system will not impact on the DP capability of the vessel.

6.6 Lubricating Oil System Emergency Generator

6.6.1 The emergency generator is provided with its own LO system. The engine driven LO pump is provided with oil supply from the wet sump of the engine. From the sump it is pumped through the LO cooler and returns to the wet sump. There are low pressure and low low pressure alarms in this system.

6.7 Lubricating Oil System Emergency Generator Failure Modes

6.7.1 Any failure of the emergency generator LO system will only affect this engine.

7. COMPRESSED AIR SYSTEMS

7.1 Starting Air System

7.1.1 The starting air system comprises two Sperre HL2-90 compressors each with capacity of $59m^3/h$ at 30 bar. Each compressor discharges compressed air through an oil/water separator into a common line to the two start air receivers. Each start air receiver has a capacity of 1500 litres. Each is fitted with a low pressure alarm. All reservoirs have relief valves fitted which vent on deck (In accordance with the advice from M119 DPVOA Engine Room Fire on DP Vessels).

7.1.2 One air receiver is isolated from the system in a fully charged condition at all times.

7.1.3 The important DP consumers of the starting air system are as follows:-

- All generator engines.
- Control air for main engine, through a 30/8 bar reducer.
- Air supply to generator emergency shutdowns.

7.1.4 The electrical supplies are arranged as follows:-

Starting air compressor 1	Aux. Swbd from 440V PS bus-bar
Starting air compressor 2	440V ESB
Working air compressor	Aux. Swbd from 440V SB bus-bar

7.2 Service Air System

7.2.1 A Sperry service air compressor is installed with a capacity of $48m^3/h$ at 8 bar. Air from this compressor is diverted through a Sperry drier prior to supplying the 8 bar system

7.2.2 The service air is used for the taut wire systemsand thruster brakes. It is also used for the clutch control of the retractable thruster.

7.2.3 Should the service air compressor fail, then a 30/8 bar reducing station is supplied from the main air receivers.

7.3 Compressed Air Failure Modes

7.3.1 Failure of one start air compressor results in the starting of the standby machine.

7.3.2 Major system leakage will result in the engines continuing to run, but without air supply to the shutdown cylinders.

7.3.3 Loss of service air pressure can be circumvented by supplying air pressure from the starting air system through a pressure reducing valve.

7.4 Compressed Air System Failure Modes

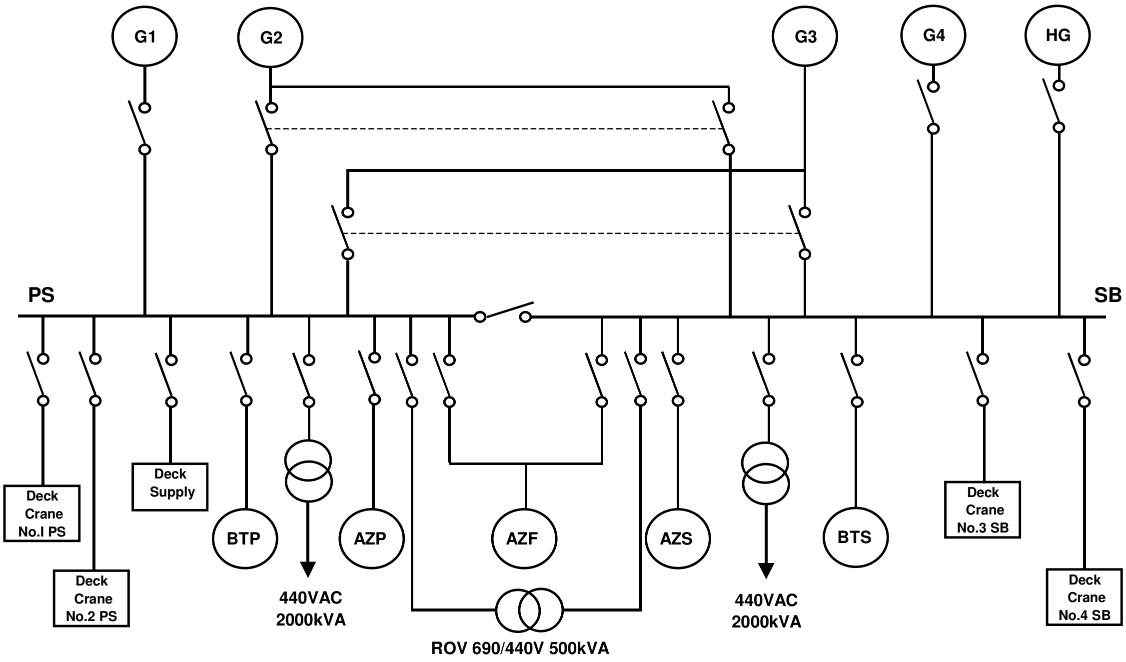
7.4.1 Compressed Air System Failure Modes

Failure Mode	Cause(s)	Probability	Local Effect	Final Effect	Criticality	Remarks
Start Air Compressor.	Mechanical failure.	Medium	Low start air pressure alarm in ECR.	Start of other compressor.	Minor	
Start Air Receiver.	Mechanical failure.	Low	Low start air pressure alarm in ECR.	Isolate affected receiver.	Minor	
Loss of start air.	Major Air system leakage.	Low	Low pressure alarm.	Engines continue to run.	Minor	Shutdown function inoperable until resumption of air pressure.

8. POWER DISTRIBUTION

8.1 690V Switchboard

8.1.1 The 690V switchboard is supplied by Ingelectric and its layout is illustrated below:



8.1.2 The main 690V switchboard consists of two independent sections:-

- 690V bus-bar Port.
- 690V bus-bar Starboard.

8.1.3 The proposed mode of operation for DP2 operations is with the breaker +20BA07.B closed between the 690V bus-bar sections. A minimum of two generators will be connected to the switchboard at any one time.

8.1.4 In the event of the bus tie opening, the reason for this should be ascertained prior to attempting to cross connect either No. 2 or 3 generators, as one of these could have been the cause of the fault.

8.1.5 A Harbour Generator can also supply power to the 690V bus-bars. This is connected to the Starboard bus-bar and can only be paralleled with one on-line main generator. This generator is not part of the DP 2 philosophy.

8.1.6 The vessel is equipped with synchroniser unit for synchronising the 690V bus bars with the other bus sections. In addition auto start facilities are installed which give start signals to the selected standby generator if necessary.

8.1.7 The main suppliers of the 690V main switchboards are:-

• Generator 1 (G 1)	2495kW
• Generator 2 (G 2)	2495kW

Generator 3 (G 3)	2495kW
Generator 4 (G 4)	2495kW
Harbour Generator (HG)	565kW

8.1.8 The main consumers of the 690V switchboards are:-

Bow Thruster Port (T1)	990kW
Bow Thruster Starboard (T2)	990 kW
Retractable Azimuth (T3)	1000 kW
Port Aft Azimuth (T4)	2450kW
Starboard Aft Azimuth (T5)	2450kW
Deck Crane 1 (Supply 1)	310kW
Deck Crane 1 (Supply 2)	310kW
Deck Crane 1 (Supply 3)	310kW
Deck Crane 1 (Supply 4)	310kW
Power to Deck	300kW
690/440V Transformer 1	2000kVA
690/440V Transformer 2	2000kVA
690/440V Transformer for ROV.	500kVA

8.1.9 The configuration of the 690VAC DP consumers is seen in table 8.1.9 below:-

Port Bus-bar	Starboard Bus-bar
Bow Thruster Port (T1)	Bow Thruster Starboard (T2)
Retractable Azimuth (T3)	Retractable Azimuth (T3)
Port Aft Azimuth (T4)	Starboard Aft Azimuth (T5)
690/440V Transformer 1	690/440V Transformer 2

Table 8.1.9 690VAC DP Consumers

8.1.10 It will be noted that the Retractable Thruster can be supplied from both bus bars. Interlocks are installed to ensure that the 690V main supply and 440V auxiliary supplies cannot be sourced from the same side of the switchboard.

8.1.11 There is one bus-tie between the 690V bus-bars, rated at 6300A.

8.1.12 The 690/440V transformers can be connected from either or both bus-bars. For DP2 purposes it is recommended that both transformers are connected, and the 440V bus-tie is split.

8.1.13 The 500kVA 690/440V transformer dedicated for ROV or other client requirements can be supplied from either side of the 690V bus and are interlocked to avoid being closed simultaneously. In the event of the ROV transformer failure, an emergency provision is available to supply the ROV switchboard directly from the 440V MSB (either side). This emergency provision is not intended for continuous use.

8.2 440V Switchboard

8.2.1 There are two sections of the 440V switchboard, Port and Starboard. Both sections can be supplied from a dedicated transformer on each 690V switchboard section

8.2.2 There is a 3200A bus-tie breaker that can connect both switchboard sections.

8.2.3 For DP2 purposes when operating with a closed 690V bus-tie the 440V bus-tie is split, with both transformers connected.

8.2.4 In the event of the 690V and 440V switchboards operating with their respective bus-ties closed and the 690V bus-tie trips, then the 440V bus-tie will also trip. If it is then desired to reconnect the 440V bus-tie, then one transformer must be disconnected to enable the bus-tie to be closed on to a dead switchboard section. Care must be taken to ensure that one transformer has sufficient capacity to supply the complete 440V switchboard prior to connecting the bus tie breaker.

8.2.5 Automatic disconnection of the 440V transformer output breaker will also occur for the following reasons:

- Over current.
- Short circuit.

8.2.6 Configuration of 440V Heavy Consumer supplies can be seen in table 8.2.6 below:

440V Busbar Port	440V Busbar Starboard
Port 440/230V Transformer	Stbd. 440/230V Transformer
Port 440/110V Transformer	Stbd. 440/110V Transformer
No.1 FW Pump	No.2 FW Pump
No.1 SW Cooling Pump	No.3 FW Pump
No.2 SW Cooling Pump	No.3 SW Cooling Pump
Engine Room Ventilation No.1	Engine Room Ventilation No.2
Air Conditioning Plant	ECR Air Conditioning
Bridge AC 1	Bridge AC 2
Start Air Compressor 1	Service Air Compressor 2
T1 FC Auxiliary Supply	T2 FC Auxiliary Supply
T4 PS Propulsion Thruster FC Auxiliary Supply	T5 SB Propulsion Thruster FC Auxiliary Supply
T4 PS Propulsion Thruster Steering gear	T5 SB Propulsion Thruster Steering gear
T4 PS Propulsion Thruster LO Pump	T5 SB Propulsion Thruster LO Pump
T3 Retractable Thruster FC Aux. Supply	T3 Retractable Thruster FC Aux. Supply
Forward Crane	A-Frame
Centre Crane	Beacon Winch FC
Taut Wire Winch 1	Taut Wire Winch 2
HiPAP Hoist 1	HiPAP Hoist 2
Crane emergency supply	Air dive switchboard
Deck Supply	Deck Supply
Emergency Switchboard	Emergency Switchboard
ROV Emergency Supply	ROV Emergency Supply
Dive Switchboard Supply	Dive Switchboard Supply
Incinerator	No.1 Main Air Compressor
No.1 Oil & FO Services	No.2 Oil & FO Services

Table 8.2.6 440VAC Heavy and DP Consumers

8.2.7 The two Oil and Fuel Oil Services switchboards supply the consumers seen in table 8.2.7 on the following page:

Oil and FO Services SWBD. 1	Oil and FO Services SWBD. 2
FO Transfer Pump 1	FO Transfer Pump 2
FO Purifier 1	FO Purifier 2
LO Purifier and heater	Tunnel Thruster 2 Auxiliary
Tunnel Thruster 1 Auxiliary	Retractable Thruster Steering Pump 1 (Supply 2)
Retractable Thruster Steering Pump 1 (Supply 1)	Retractable Thruster Steering Pump 2 (Supply 2)
Retractable Thruster Steering Pump 2 (Supply 1)	Retractable Thruster UGB LO Pump (Supply 2)
Retractable Thruster UGB LO Pump (Supply 1)	Retractable Thruster UGB LO Pump (Supply 2)
Retractable Thruster UGB LO Pump (Supply 1)	

Table 8.2.7 Oil and FO Services Switchboard Consumers

8.3 230V Switchboards

8.3.1 The 230V switchboard is split into two independent sections and can be connected by a breaker. Each section is supplied via a 440/230V transformer from its respective 440V bus-bar. It is recommended that the bus tie breaker between the 230V remains open during DP operations.

8.3.2 The DP important consumers of the 230V Main Switchboards are as seen in table 8.3.2 below:

Port 230V Bus-bar	Starboard 230V Bus-bar
Bridge Services Supply	Bridge Services Supply
Engine-room Services No.1	Engine-room Services No.2
PS Main Propulsion FC Aux. Supply (T4)	SB Main Propulsion FC Aux. Supply (T5)
Azimuth FC Aux. Supply (T3)	Azimuth FC Aux. Supply (T3)
PS Bow thruster FC Aux. Supply (T1)	SB Bow thruster FC Aux. Supply (T2)
DP UPS 1	DP UPS 2

Table 8.3.2 230V Bus-bar DP Consumers

8.3.3 It will be noted that both the Bridge Services and the Engine-room Services have two supplies from either side of the 230V bus bar. The DP important consumers of these boards are as seen in table 8.3.3 below:

Bridge Services 230V Switchboard	ER Services 230V Switchboard
Voyage Data Recorder	Port Propulsion Converter UPS
DP UPS 3	Stbd. Propulsion Converter UPS
Independent Joy Stick (cJoy)	Tunnel Thruster Converter 1 UPS
Public Address System	Tunnel Thruster Converter 2 UPS
Automatic Telephone System.	Retractable Thruster Converter UPS
	Port 690\440V Transformer Control Supply
	Stbd 690\440V Transformer Control Supply
	Automation UPS

Table 8.3.3 Bridge and ER Services Switchboards DP Consumers

8.4 110V System

8.4.1 The 110V switchboard is supplied from 440V/110V transformers from each side of the 440V bus bars.

8.4.2 There are two sections of the 110V switchboard and with the provision of a bus-tie fitted between them, and this should remain open during DP operations.

8.4.3 The Port 110V switchboard provides the main power source for the 110V Bridge Services Switchboard, and failure of this supply will instigate an automatic change over to supply from the 110V ESB.

8.4.4 The 110V Bridge Services Consumers relative to DP operations are as seen in Table 8.4.4 below:

Bridge Services 110V Swbd.
Voyage Data Recorder
DP UPS 3
Public Address System
DP Joystick
Automatic Telephone System.

Table 8.4.4 110V Bridge Services DP Consumers

8.4.5 Primarily the 110V system is used for vessel lighting and providing power to the 24VDC systems (see Section 8.5).

8.5 24VDC Systems

8.5.1 There are five independent 24VDC systems, four using charger/rectifiers with a battery back up should the main supply fail, and the remaining system is a battery charger only for the Emergency Generator start batteries. The source of supplies for these systems can be seen in Table 8.5.1 below:

System	Supply
Bridge 24V Swbd	Bridge Serv.110V SWB. & 110V ESB
ER 24V Swbd No. 1	110V E.R. Port Lighting SWB.& 110V ESB
ER 24V Swbd No. 2	110V E.R. Stbd Lighting SWB.& 110V ESB
GMDSS	230V MSB Port & 230V MSB Stbd.
Emerg DG Batteries	110V ESB (One supply for each charger)

Table 8.5.1 24VDC Power Supplies

8.5.2 Failure of one power supply to the Bridge or Engine-room 24VDC distribution boards is alarmed.

8.5.3 Source of 110V charging power is selected by a manual switch located over the UPS batteries located in the starboard forward corner of the ECR.

8.5.4 The DP related consumers supplied by the Bridge Services 24V distribution panel can be seen in the Table 8.5.4 on the following page:

Bridge Services 24VDC Swbd.
Voyage Data Recorder
Gyro-1
Gyro-2
Gyro-3
DP Alert System
DGPS Spotbeam Aerial Splitter
DGPS Inmarsat Aerial Splitter
MRU Serial Splitter
Fire Detection Central – machinery loop
Main Automatic Telephone Central
Engine Telegraph
Wind Sensor Splitter

Table 8.5.4 Bridge Services 24V DP Consumers

8.5.5 The two Engine-room Service 24VDC distribution panels are listed in Table 8.5.5 below:

ER 24VDC Swbd. No. 1 Consumers	ER 24VDC Swbd. No. 2 Consumers
Interconnection with ER 24V Swbd No. 2	Interconnection with ER 24V Swbd No. 1
No. 1 AE Start/Stop cabinet and automation	No. 3 AE Start/Stop cabinet and automation
No. 2 AE Start/Stop cabinet and automation	No. 4 AE Start/Stop cabinet and automation
Port Propulsion Azimuth main supply	Port Propulsion Azimuth back up supply
Stbd. Propulsion Azimuth back up supply	Stbd. Propulsion Azimuth main supply
Tunnel Thruster No. 1 main supply	Tunnel Thruster No. 1 back up supply
Tunnel Thruster No. 2 back up supply	Tunnel Thruster No. 2 main supply
Retractable Thruster main supply	Retractable Thruster back up supply
PMS Supply No. 1	PMS Supply No. 2
Harbour set supply No. 1	Harbour set supply No. 2
Beacon Signalization supply no.2	Beacon Signalization Supply no. 1

Table 8.5.5 ER Services 24V Consumers

ER 24VDC Swbd. No. 1 Consumers	ER 24VDC Swbd. No. 2 Consumers
Bridge Supply (Spare)	Harbour CB 24V
Paint CO2 Supply No.1	Paint CO2 Supply No.2
Chemical CO2 Supply No.1	Chemical CO2 Supply No.2
Automation Cabinets DPU 1, 2 and 3	Automation Cabinets DPU 4, 5 and 6
Galley Damper / CO2 / Cold Store	Hydramarine Deck crane emergency stop
Automatic telephones relays	Signal Beacons
ER CO_2 supply No. 1	ER CO_2 supply No. 2
Port 690/440V Trafo temperature control	Stbd. 690/440V Trafo temperature control
ER Automatic telephone relays	Sound powered telephone
110V MSB supply No. 1	110V MSB supply No. 2
ECR Alarm Server No.1	ECR Alarm Server No.2
Generator No. 1 Circuit Breaker 24V supply	Generator No. 3 Circuit Breaker 24V supply
Generator No. 2 Circuit Breaker 24V supply	Generator No. 4 Circuit Breaker 24V supply

Table 8.5.5 ER Services 24V Consumers (continued)

8.5.6 In the event of one ER 24VDC system failing completely, there is an interconnection that will connect both ER systems together.

8.5.7 The Emergency Services supplies 24V to the starting batteries for the Emergency Generator only.

8.6 440V Emergency Switchboard

8.6.1 The 440V ESB is supplied from both sides of the main switchboard with manually operated breakers. Interlocks are arranged to prevent both breakers being on line simultaneously.

8.6.2 On failure of a 440V supply from the main switchboard the EDG will start and connect to supply the ESB. Protection must be installed to prevent the operation of either manual circuit breaker from the 440V switchboards whilst the EDG is on line.

8.6.3 The 440V emergency switchboard is located in the emergency generator room and the important consumers are as follows:-

- Starting air compressor No.2.
- 440/110V 25KVA Transformers.
- Diver Emergency Supply.

- Emergency Fire Pump.
- Watertight Door system.
- LO Pre lubricating pumps for all generators.
- Engine Room supply No.2.
- EDG room supply fan.
- Engine room exhaust fan.

8.7 110V Emergency Switchboard

8.7.1 The 110V emergency switchboard is located in the emergency generator room and is supplied from either of two transformers from the Emergency 440V switchboard.

8.7.2 The important consumers are as follows:-

- Navigation Lights.
- Charger/rectifiers for all 24V systems.
- Emergency generator Battery Charger.
- Emergency Lighting DB.

8.8 Failure Modes of the Power Distribution

8.8.1 Failure of a 690V, 440V and 230V bus bar section will only result in the loss of consumers connected to them if each switchboard is configured correctly with the bus-ties open. Each system is configured so that the loss of a bus bar section will not result in the loss of more than half of the vessel’s systems, thus DP will be maintained, but with reduced capability.

8.8.2 Failure to ascertain the cause of a main bus-tie opening must be ascertained before attempting to cross connect generator 2 or 3 to the other switchboard section.

8.8.3 Failure of supply from the Main 440V switchboard to the Emergency Switchboard will result in the Emergency Generator starting automatically and supplying all the 440V and 110V Emergency Switchboard consumers.

8.8.4 Failure of the 110V power supply to the 24V systems will result in back up supplies from the battery UPS units, which should supply the systems for at least 30 minutes.

8.9 Power Distribution Failure Modes

8.9.1 Power Distribution Failure Modes

Failure Mode	Cause(s)	Probability	Local Effect	Final Effect	Criticality	Remarks
690V Bus-bar.	Failure of one DG.	Medium	Reduced power available.	PMS reduces load requirements.	Medium	Reduced station keeping ability.
	Short circuit Earth fault Overload	Low	Reduced power available. Loss of one side.	Loss of one half of the generating capacity, and all thrusters powered from that side.	Medium	Reduced station keeping ability.
440V Bus-section.	Failure 690V bus bar.	Medium	Reduced power available. Loss of one side.	Failure of all consumers supplied by that particular section. EDG may start and connect to supply ESB.	Medium	Loss of 440V will effectively lose one half of all propulsion and reduced station keeping ability.
	Short circuit Earth fault Overload	Low			Medium	
230V MSB.	Failure of 440V section.	Medium	Alarm. Loss of one side.	Failure of all consumers supplied by that particular section.	Minor	Loss of 230V will effectively lose one half of all propulsion and reduced station keeping ability.
	Short circuit Earth fault Overload	Low			Minor	
110V Swbd.	Short circuit Earth fault Overload	Low	Loss of lighting. Loss of power supply to UPS systems.	UPS supply power until power restored to ESB. Change over supply transformer.	Minor	No effect on DP.
	Failure of 440V section	Medium			Minor	
	Loss of transformer	Low			Minor	

8.9.1 Power Distribution Failure Modes (continued)

Failure Mode	Failure Mode	Failure Mode	Failure Mode	Failure Mode	Failure Mode	Failure Mode
440V / 110V ESB.	Loss of 440V MSB supply.	Low	Auto start of Emergency Generator.	Emergency generator supplies 440V and 110V ESBs.	Minor	No effect on DP.
	Short circuit Earth fault Overload	Low	Loss of 440V and 110V ESB.	Loss of all ESB consumers. UPS units switch to alternate source or revert to battery backup.	Minor	

8.10 Power Management System

8.10.1 The PMS performs the following functions:

- Diesel generator control. This controls manual start/stop, manual generator coupling with auto-synchronization, start/stop selection, standby selection, load dependant start/stop and automatic balanced or unbalanced load sharing
- Start blocking for crane
- Load imbalance monitoring
- Reverse power protection
- Blackout prevention through load reduction and preferential tripping
- Blackout monitoring

8.10.2 There are four ship operation modes:

- DP or Diving Mode. A maximum of three generators running in closed bus-tie mode. All propellers and thrusters running. All protection features active.

- Manoeuvring Mode. With three generators running with a closed bus-tie or four generators running (two on each MSB) in open bus-tie situation. All propellers and thrusters running. With reserved power for miscellaneous consumers.

- Open Sea Mode. A maximum of three generators running and all thrusters ready for use. Power limitation active according to network demand. With reserved power for miscellaneous consumers.

- Finished With Engines. The PMS will reset all limitations for other modes and will control the amount of generators running.

8.10.3 The PMS will restore power to the MSB after a blackout. The PMS detects that a blackout has occurred when the blackout monitoring function is active and all generator breakers are open. The PMS sends a start signal to all available generators as selected on the operator set start priority. The first available running generator will be connected directly, with subsequent generators being synchronized and connected.

8.10.4 The automatic stopping of a generator is to be set at the operator's discretion during all DP operations.

8.11 PMS Failure Modes

8.11.1 Complete failure of the PMS will result in the switchboard reverting to droop mode, and the generator governors and operators controlling the switchboard loading.

8.11.2 The PMS is supplied from ER 24V system. Failure of any one supply will only affect one PLC of the PMS and will result in the system switching over to the alternative PLC if the failed PLC was in primary mode. If the failed PLC is the standby PLC then status of primary PLC remains unchanged. In both cases an alarm is raised in the IAS. The IO modules are dual supplied.

8.12 Integrated Alarm System

8.12.1 A Praxis Mega-guard Machinery Control and Monitoring System (MCMS) is installed. This system runs on dual redundant networks. The system processes all alarm signals from all mechanical equipment and associated systems through a series of six Distributed Processing Units (DPU) which are supplied from the Engine-room 24VDC panels.

8.12.2 The DPUs collate all the I/O signals from the machinery and systems and transmit these signals through the network to the operating stations.

8.12.3 All operating stations work on the Windows XP operating system. They also contain a marinised PC and TFT screen, with keyboard and tracker ball.

8.12.4 Operating stations are located in the ECR and on the Bridge. The Bridge unit is a slave repeater and only interactive for Ballast control.

8.13 Failure modes of IAS System

8.13.1 Power supply failure will result in changeover to alternative supply from other switchboard.

8.13.2 Failure of any one server or network does not impact functionality.

8.13.3 Failure of the complete IAS system will result in all propulsion continuing as before.

8.14 PMS and IAS Failure Modes

8.14.1 PMS and IAS Failure Modes

Failure Mode	Cause(s)	Probability	Local Effect	Final Effect	Criticality	Remarks
PMS failure	Supply failure	Low	Alarm in ECR. One PLC loses power.	Control reverts to standby PLC if primary PLC is affected.	Minor	Only one PLC is affected.
	System failure	Low	Alarm in ECR.	Load sharing changed to droop mode.	Major	No blackout protection.
IAS failure	Short circuit Earth fault Network failure. DPU failure	Low	Alarm in ECR.	All propulsion continues as before.	Minor	
	Power failure	Low	Alarm in ECR.	System switches to UPS supply.	Minor	

9. PROPULSION

9.1 General

9.1.1 All thrusters are propelled by Indar motors and speed controlled by Ingeteam frequency converters.

9.1.2 Each FC has its own internal cooling pump and system which is cooled by the vessel's auxiliary LTFW system.

9.1.3 Control supply of the FC is from a 24VDC UPS, which is supplied from MSB 230V supply. On failure of these supplies control will revert to UPS battery backup.

9.1.4 Failure of the UPS will stop the FC.

9.2 Tunnel Thrusters

9.2.1 There are two fixed pitch Lips tunnel Bow thrusters, driven by electric motors controlled by frequency converters, rated at 990kW each.

9.2.2 The tunnel thrusters can be started or stopped from the forward or aft bridge console, or locally. Emergency stop can be effected from forward and aft bridge consoles, from the main switchboard (breaker) or locally if required.

9.2.3 The electrical supplies for the tunnel thrusters are arranged as follows:-

• Port Bow Tunnel (BT1)	690V/440V/220V PS bus-bar
• Stbd. Bow Tunnel (BT2)	690V/440V/220V SB bus-bar

9.2.4 The tunnel thrusters are electronically remote controlled by the Lipstronic system, which will control the speed of the electric motor by changing the signal to the frequency converter.

9.3 Tunnel Thruster Failure Modes

9.3.1 Any failure will affect one thruster unit only.

9.3.2 Failure of LTFW cooling supply or the drive internal cooler unit will result in a gradual build up in temperature, ultimately resulting in the shutdown of the thruster.

9.3.3 Failure of command signal from the DP system will result in the thruster failing to frozen (last known) speed.

9.3.4 Failure of feedback signal to the DP system will result in the thruster operating normally and an alarm on the DP.

9.4 Tunnel Thruster Failure Modes

9.4.1 Tunnel Thruster Failure Modes

Failure Mode	Cause(s)	Probability	Local Effect	Final Effect	Criticality	Remarks
LO Pump	Electrical or mechanical failure.	Low	Low pressure alarm in ECR.	Thruster stopped manually.	Medium	
24V Supply to TCU.	Electrical Failure.	Low	Alarm in ECR and on DP panel.	Auto Change over to 24V back up. No loss of position.	Minor	
DP command signal	Wire break.	Low	Alarm on DP.	Thruster speed frozen at last speed.	Minor	DP system increases load on remaining thrusters to compensate.
DP feedback signal	Wire break.	Low	Alarm on DP.	Thruster operates normally.	Minor	DP reverts to estimated feedback.
FC 230V fan supply failure	Electrical failure.	Low	FC shut down.	Thruster shuts down.	Minor	DP system increases load on remaining thrusters to compensate.
FC Cooling Failure	LTFW or dedicated cooling pump failure.	Low	Thruster drive temperature rise.	Thruster shuts down on high temperature.	Minor	DP system increases load on remaining thrusters to compensate.
Power Supply failure (230V) to FC UPS	Breaker or short circuit.	Low	Alarm in ECR.	System reverts to UPS battery back up.	Minor	
FC Control UPS failure	Breaker or short circuit.	Low	Failure of frequency converter.	Thruster shuts down.	Minor	DP system increases load on remaining thrusters to compensate.

9.5 Azimuth Thrusters

9.5.1 The vessel is equipped with two fixed pitch azimuth propellers aft rated at 2450KW, and a retractable fixed pitch propeller forward rated at 1000KW, all manufactured by Wärtsilä Lips.

9.5.2 Two fixed pitch thrusters (T4 and T5) are located in their own spaces at the after end of the vessel. These thrusters are also used for navigational purposes.

9.5.3 Each thruster is supplied from the 690V switchboard, and is driven by a variable frequency drive. The forward thruster has a speed range of 0-1800 rpm (reversible) and the after thrusters have a speed range of 0-900 rpm.

9.5.4 Each after thruster is fitted with one hydraulic pump which supplies two hydraulic steering motors.

9.5.5 The forward retractable thruster has two independent electrically powered steering pumps. The steering oil pump also provides power to raise and lower the unit

9.5.6 A lubrication oil pump supplies oil to the upper and lower gearboxes on the retractable thruster.

9.5.7 On each after thruster a lubrication oil pump circulates the system oil and provides the static pressure head on the system.

9.5.8 Each thruster shaft is fitted with an air powered brake. The air is supplied from the Service air system at 8 Bar. The forward thruster is also fitted with an air powered clutch arrangement.

9.6 Azimuth Thruster Failure Modes

9.6.1 Failure of one hydraulic steering motor on the after thrusters will only result in slower rotation of the thruster and a prediction error on DP panel.

9.6.2 Mechanical failure of one of the two electric steering motors on the forward thruster will result in slower azimuth rotation of the thruster. The DP Control System will increase the load on the tunnel thrusters to compensate for this loss. This failure may cause a prediction error on DP panel.

9.6.3 Failure of an after hydraulic (steering) pump will instigate an alarm and the thruster will remain running.

9.6.4 Failure of the gearbox oil lubrication pumps will give an alarm only.

9.6.5 Failure of a frequency converter, due to electrical faults or high cooling water temperature will result in the stopping of the thruster.

9.7 Azimuth Failure Modes

9.7.1 Azimuth Failure Modes

Failure Mode	Cause(s)	Probability	Local Effect	Final Effect	Criticality	Remarks
24V Supply to TCU.	Electrical Failure.	Low	Alarm in ECR and on DP panel.	Auto Change over to 24V back up. No loss of position.	Minor	
Maladjusted Feedback.	Feedback potentiometer or linkage loose.	Low	Degraded position keeping.	System should compensate.	Minor	
Propulsion Thruster Steering motor failure.	Mechanical or electrical failure.	Low	Propulsion thruster will still have one steering motor.	Thruster azimuths slower. DP system compensates. Prediction Error on DP.	Minor	
Retractable Thruster Steering Motor failure.	Mechanical or electrical failure.	Low	Thruster azimuths at slower pace and possibly a prediction error will occur.	DP system compensates for thruster loss.	Minor	
After Thruster Steering pump.	Mechanical or electrical failure.	Low	Alarm in ECR.	DP system compensates with remaining thrusters.	Minor	
Gearbox LO Pump.	Mechanical or electrical failure.	Low	Alarm in ECR.		Minor	
Power Supply failure (230V) to FC UPS.	Breaker or short circuit.	Low	Alarm in ECR.	System reverts to UPS battery back.	Minor	
FC Control UPS failure.	Breaker or short circuit.	Low	Failure of frequency converter.	Loss of thruster.	Minor	DP system increases load on remaining thrusters to compensate.
FC 230V fan supply failure.	Electrical failure.	Low	Failure of frequency converter.	Thruster will stop.	Minor	DP system increases load on remaining thrusters to compensate.
FC Cooling Failure.	LTFW or dedicated cooling pump failure.	Low	FC temperature rise.	Thruster shuts down on high temperature.	Minor	

9.7.1 Azimuth Failure Modes (continued)

Failure Mode	Cause(s)	Probability	Local Effect	Final Effect	Criticality	Remarks
DP command signal.	Wire break.	Low	Alarm on DP	Thruster speed frozen at last known speed.	Minor	DP system increases load on remaining thrusters to compensate.
DP feedback signal.	Wire break.	Low	Alarm on DP	Thruster operates normally.	Minor	DP reverts to estimated feedback.

10. DP CONTROL SYSTEM

10.1 General

10.1.1 The Vessel is fitted with a Kongsberg K-Pos Dynamic Positioning Control system in order to comply with ABS+DPS-2.

10.1.2 The DP system interfaces various vessel control systems in order to keep position/heading when DP mode is chosen.

10.2 K-Pos Operator Stations

10.2.1 The K-pos consists of two Operator Stations (DP OS), both located at the after end of the bridge. Each OS consists of the following components;

- Operator panel with joystick and pushbuttons
- A monitor for the operator station
- A slave-monitor for the monitoring of the other operator station
- OS computer.

10.2.2 The OS has minimum hardware; the computer interfaces the operator with the operating panel and the display. The sensors, references and thrusters are selected and deselected using a Windows XP application. Alternatively buttons are also provided on the console for quick operations and operational mode selection. A joystick is provided on the OS for manual control of the thrusters and for semi manual yaw, surge and sway control. Operator can select joystick control of either or of two movements and the DP controls the other.

10.2.3 The screen of the console is divided into one large area on the right and two smaller areas on the left, the size of these areas cannot be changed. Each of the areas can display a separate page of information, which can be selected by the operator.

10.2.4 Alarms are displayed when the “Alarm view” button on the keypad is pushed. All the alarms are presented on an overlapping window on the screen of the console where the button is pushed. When an operator has to input information this is also done using overlapping windows, which always show up at the same location on the screen. The cursor is positioned directly on the input window. The pointer can be moved using a trackball and selections are made using three buttons in front of the trackball.

10.2.5 Colours can be selected from different palettes, (e.g. Daylight and Night). The 'Night' palette has different colours and easy to split information and commands. The push buttons on the keypad are either white with black text, or black with white text. The white buttons are “double push” buttons, while the black buttons are “single push” buttons; in case a button is pushed an indicator light will light.

10.3 DP Computers and Network

10.3.1 The DP System is a Kongsberg Maritime K-Pos dual redundant system.

10.3.2 Connections to the position-reference systems, sensors, thrusters and power plant are made via conventional signal cables and serial lines.

10.3.3 The controller unit and the operator station communicate via a dual network. The hub is located inside the operator station console.

10.3.4 There are two independent but linked microprocessors (Single Board Computer – RCU501) which monitor input data received from a range of sensors using a master/slave relationship and generate the signals to the thrusters required for position and heading control. The operating system for the console computers is Windows XP. This is a shell used for display purposes only. The actual control is done by the computers (RCU501) in the Kongsberg computer cabinet (DPC-2), which is located in the after Bridge.

10.3.5 Computers and all interface boards in the DPC-2 are located in the upper cabinet whereas power supplies are sited in the lower cabinet. There are analogue boards for reference system signals, and there are isolation amplifiers on the signals for the thrusters. Although the CPUs and the power supplies are separated, the interface boards are serial linked but common and both computers are connected to each board.

10.3.6 One of the functions of the Power Supply Units (PSU) within the DP cabinet is, to generate a stable reference voltage for the potentiometers used for the feedback signals.

10.3.7 The two computers in the K-Pos operate in parallel each receiving inputs from sensors, reference systems, thrusters and operator and each performing the necessary calculations. However, only the on-line computer (master) controls the thrusters. Switchover between the computers (master/slave) may be either automatic or manual. It is automatic if failure is detected in the on-line computer. Continuous comparison tests are performed to check that the two computers read the same inputs and give the same outputs. If a difference occurs, warnings and alarms are reported from each computer. The weak point in a dual redundant system is in determining which computer is wrong. The operator therefore could choose the wrong one.

10.3.8 In DP Class 2 operations at least three position references must be available, whereby the system can exclude an incorrect or unstable reference and still keep a good position with some quality degradation. The Consequence Analysis warning given by Kongsberg does not take this into account and reacts purely on low power availability or insufficient thrust (thrusters and generators).

10.4 DP Control Modes and Functions

10.4.1 The standard DP control modes are implemented which are standby, manual (joystick) and auto position. Mixed modes between manual and auto are automatic control of yaw, surge-axis and sway-axis either separately or combined. When all three are selected an automatic switch to AUTOPOS mode is made.

10.4.2 The wind, gyro or MRU sensors used by the DP system cannot be directly selected from the keypad. Instead, a dialogue box on the screen is used where the preferred sensor has to be selected. On the keypad a button only controls whether the gyro, MRU and wind inputs are selected or not. Note! If a gyro falls out it has to be manually enabled/reselected in the dialogue box. This is not the case for the other sensors.

10.4.3 A standard median test is implemented which will detect a seemingly perfect position measurement, e.g. dragging transponder. A parameter is that at least three position reference systems have to be selected and accepted by the DP computer. Also a high variance test is used to deselect those position reference systems which show a high variance pattern over a prolonged time period. It is required that sufficient position reference systems are selected and accepted by the DP system.

10.4.4 The DP mathematical model is using various historical input data to predict values/position and compare with actual readings. The computer calculates the required force and thrusters to be used in order to keep required set-points. To achieve a good mathematical model the vessel has to be in position for some time in order to build up the model.

10.4.5 DP consequence analysis software function will be activated automatically when mode DP Class 2 is selected. The consequence analysis function within the K-Pos software only runs when the vessel is in present position and on present heading. E.g. if the vessel is in auto track mode, or on the move towards a set point in AUTOPOS mode, the analysis will not run. There is no information about this within the K-Pos system help functions. The operator has to be aware of this.

10.5 DP Sensors

10.5.1 The vessel is fitted with following DP Sensors:

- 3 x Wind Sensors.
- 3 x Gyros.
- 3 x MRU

10.6 Wind sensor

10.6.1 There are three Gill WindObserverII ultrasonic sensors and these are located on top of the main mast. There are 2 x Observator OMC-139 wind displays installed on the aft bridge and 1 in forward bridge console. All wind sensors give input to the DPC-2.

10.6.2 Failure of a wind sensor is alarmed for sensor difference in both speed and azimuth; however differences are frequent because of local turbulence.

10.6.3 In cold weather it is possible for ice to cause a sensor failure. It is recommended that heaters should be fitted if it is envisaged that the vessel is to operate in cold climates.

10.7 Gyro Compass

10.7.1 There are three Sperry/C-Plath Navigat MK1 gyros onboard. All gyros are located on the Bridge. Each gyro sends signals in a general format (NMEA) to the DPC 2 system.

10.7.2 Signals from Gyro 1 are sent to DPC 2, DGPS 1, HiPAPs, Compass Monitor and Survey Box. Signals from Gyro 2 are sent to DPC 2, DGPS 2, HiPAPs, Compass Monitor and Survey Box. Signals from Gyro 3 are sent to DPC 2, Cc 1.

10.7.3 Failure of a gyro is alarmed for gyro difference in the DPC 2. Sudden failure of the gyro in use will result in the next enabled gyro to take over, however a slow drift off may result in heading drift off (within the normal footprint), until the difference is high enough for the voting to reject the failed gyro. There will however often be a visual reference available to detect unwanted heading moves of the vessel.

10.8 Motion Reference Unit (MRU)

10.8.1 There are three MRUs installed, supplied by Kongsberg Maritime.

10.8.2 The MRU system uses solid state devices to measure the roll and pitch (MRU 2) and heave (MRU 5 only). The MRUs have power supply from the DP system, (DPC-2). (The MRU signals are fed into the DPC networks in blocks U41, U64, U65 and U67 inside the computer cabinet in the Electronics Room).

10.8.3 The MRU's signals are sent to the following systems:

MRU 5 (No. 1)	DPC-2, HiPAP 500, HMS100 and Survey (via serial splitter)
MRU 2 (No. 2)	DPC-2 and HiPAP 350
MRU 2 (No.3)	DPC-2 and Survey

10.8.4 A failure of a MRU could be caused by power supply failure or failure of the unit itself. An undiagnosed MRU failure is a potential major problem that will increase in severity depending on the water depth. All the position reference systems depend on the MRU for correction of inclination in roll and pitch, the most dependant references being the acoustics. Failure could result in a position shift within the normal footprint. Identification of the failed unit after a sensor difference alarm may be possible.

10.8.5 Failure of MRU 1 fails HiPAP 1 acoustic system; failure of MRU 2 fails HiPAP 2. An undiagnosed MRU failure that causes a shift in position of the acoustics should result in the acoustics being rejected by the voting/median test and voting of the DPC 2. In deep water the problem is that the update rate for the acoustics is limited by the speed of sound in water unless signal stacking is possible. The DGPS is not so limited and thus it is difficult to weight these systems appropriately.

10.9 Position Reference Systems

10.9.1 The vessel is fitted with following positioning reference systems:

- 2 x Seatex DPS122
- 1 x HiPAP 500
- 1 x HiPAP 350
- 1 x Fanbeam
- 2 x Taut Wires

10.10 DGPS systems

10.10.1 There are two Differential Global Positioning Systems (DGPS) with differential corrections provided by the IALA MF signals, through antennae from the official net of stations selectable in the DP system.

10.10.2 Both Seatex 122DPS receivers have their own antenna for differential corrections, through DGPS Splitters. Two Seastar/Fugro 3510LR demodulators are used to receive corrections, DGPS 1 from Spotbeam and DGPS 2 from INMARSAT.

10.10.3 The DGPS position signals are fed into the DP computers. The antennas are located on the main mast and cabling is routed in the common cable gate from the mast down. Their location complies with the guidelines set out in IMCA Safety Flash 10/08 where all DGPS antennae are located not less than 2metres from each other.

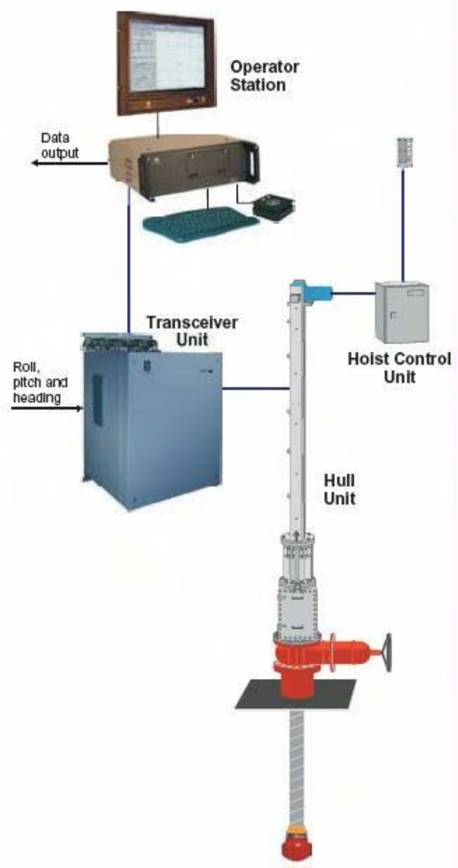
10.10.4 A DGPS Repeater is used to send GPS signals to both gyros to correct the deviation of the gyros, depending on the latitude and speed of the vessel. In case of a failure of the GPS input signal to the gyros an alarm is given, however the gyros remember the last known position, so therefore the DP system will not be affected by this type of failure, but the operator alerted to a major difference between desired vessel heading and incorrect gyro heading, and the affected gyro can be deselected. This failure has been the subject of an IMCA Safety Flash (09/08) which highlights erroneous DGPS signals can affect latitude and speed inputs to the gyros and recommends that these should be manually set.

10.11 HiPAP Systems

10.11.1 The vessel is equipped with two HiPAP hydro acoustic systems, a Type 350 and Type 500. The systems are set up with Super Short Base Line (SSBL).

10.11.2 The system is named from "**Hi**gh **P**recision **A**coustic **P**ositioning" system and is designed for all water depths from very shallow looking horizontally at a transponder to deep water (2000m) looking straight down with a standard unit. The HiPAP transducers extends below the hull and uses a semi spherical transducer, with over 230 elements for HiPAP 500 and about 46 elements for the HiPAP 350 unit, and electronic controls that enables narrow beam transmission and focused reception in the direction of the transponder, thus reducing the noise that would otherwise be received from other areas of the sphere.

10.11.3 The system calculates a three dimensional sub sea position of a transponder relative to the vessel mounted transducer unit. The directional stability of the unit is obtained firstly fixing the transponder location by a wide beam and subsequently by aiming a narrow reception beam towards the transponder. The system uses a digital beam form, which takes its input from all the transducer elements.



HiPAP, Courtesy: Kongsberg Maritime

10.11.4 The system controls the beam dynamically so it is always pointing towards the target, roll, pitch and yaw signals are input to the tracking algorithm to direct the beam in the correct direction thus enabling the correction for these motions to be effectively applied continuously.

10.11.5 The system calculates a variance for its measurements; determine the known system accuracy and standard deviation. The HiPAP has a built-in Kalman filter, which improves the stability and accuracy of the initial narrow beam guidance but does not interfere with raw fixed data being sent to the DP control computers.

10.11.6 Each HiPAP receives its heading from one gyro. The VRS signal is fed from one MRU to the HiPAP. In the current setup, both gyros and MRU are available for selection at both HiPaPs, though only one needs to be selected. It should be noted that HiPaP 500 always works with MRU 1 (MRU 5 model). The Transceivers can also be inter-switched between the consoles increasing redundancy options.

10.11.7 The HiPAP signals are sent to the DP system via the LAN network.

10.11.8 Noise interference is generally the typical problem of acoustic systems. The transducers are mounted far apart and a reasonable distance from the thrusters. When working in heavy weather noise turbulence, thruster interference and vibrations may cause occasional signal loss.

10.11.9 Failure of the acoustics can also be caused by dragging or lifting of one transponder, by transponder failure or battery failure. These are largely a matter of good procedures. If only one transponder is deployed for both systems the result is a single failure that will make both HiPAP systems unavailable. No single reference failure should be critical provided sufficient other references are on-line so that it can be rejected by the DPC 2 median check and voting. (Two DGPS and one acoustic position reference do not count as three position references in line with IMO MSC 645).

10.12 Fan Beam

10.12.1 An MDL Mk4 Fanbeam® is a laser based position reference system, which can input the vessel's relative position from a fixed structure, into the DP system, to be used in conjunction with other position reference systems.

10.12.2 The system uses the principle of laser range finding by measuring the time taken for a pulse of laser light to travel from the laser source to a target and back to the detector. The requirement to have an accurately pointed laser transmitted from a moving platform to a stationary target is extremely difficult to attain but by using special laser optics which transmits a laser beam in a 20° vertical fan this has been achieved. By scanning this fan horizontally the target can be accurately tracked and have its bearing relative to the vessel's heading and range determined. This information is then inputted into the DP system.

10.12.3 A pulse generator drives the infrared semiconductor laser diode at a rate of 7500Hz to produce the 20° laser fan. These light impulses are adjusted for the line of sight and emitted by the transmitting lens to produce a vertically diverging and horizontally parallel beam. The reflected beam is picked up by the receiving lens and converted to an electrical signal by a photo diode. The time interval measured between the transmitting and receiving of the beam is used to compute the range.

10.12.4 The accuracy of the horizontal angle is achieved by detecting every echo from the laser and reading the echo for each echo. Once the laser has passed over the target the angles are averaged, providing an angle to the centre of the target. So accuracy is not dependant on target size. The echo signals are averaged to increase the range accuracy. To achieve a range accuracy of +/-20cm at least five echoes are required from the target.

10.12.5 The scanner is mounted on a rotating table which is driven by a stepper motor and a precision worm and wheel that results in a resolution of 0.01°. A high accuracy optical encoder mounted directly on the laser shaft measures the angular position of the laser.

10.12.6 The scan speed is automatically controlled by the system software according to the target range with parameters seen in Table 10.12.6 on the following page:

Target Range	Fanbeam® Speed
<100m	50°/second
100-250m	30°/second
250-500m	15°/second
500-1400m	10°/second
>1400m	5°/second

Table 10.12.6 Fanbeam® Scan Speed

10.12.7 The equipment configuration can be seen in the figure 10.12.7 below.

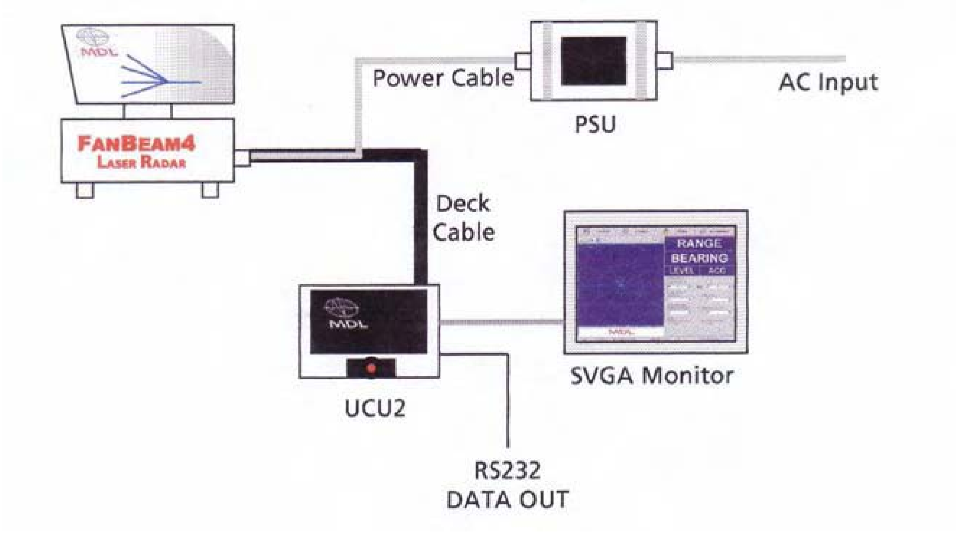


Figure 10.12.7 Fanbeam® Equipment Configuration

10.12.8 The scanner is located in such a position that it allows a clear line of sight in all directions where the targets are to be installed.

10.12.9 The scanner head can rotate through 360° and has vertical adjustment of +/- 15° in 5° steps which allows for large variations between the height of the vessel and target.

10.12.10 The quality and type of material used for reflectors are critical to the reliable operation of the Fanbeam®. Good quality reflective tape can be used on a cylindrical mounting of no less than 150mm and no more than 250mm diameter and 100mm in length. This will give a good target up to 150m, (depending on conditions). Retro Prism will give good accuracy between 150 and 1000metres, (depending on conditions), as they can reflect the laser beam +/- 30° from the prism centre line. For accuracy between 1000 and 2000m a stack/cluster of prisms is required.

10.12.11 It is essential that the targets are mounted in areas that are clear of obstructions and away from lights and other surfaces containing reflective material, (e.g. life rafts or lifeboats). They should also not be located close to walkways where reflective strips on coveralls or jackets may cause confusion in which target the Fanbeam® is locking on to.

10.13 Fanbeam® Failure Modes

10.13.1 Typical failures modes of the fanbeam system can be seen below:

- Signals can be blocked by dirty transmitting or receiving lenses
- The acquisition of false targets, e.g. reflective tape on working gear, lifeboats etc.
- Signals can be distorted by a low rising or setting sun
- Inclement weather, e.g. heavy rain, snow or fog can reduce system efficiency
- Loss of the serial link
- Loss of 28VDC supply from PSU
- Loss of encoder feedback
- Seizure of scanner head.

10.14 Taut Wires

10.14.1 The vessel is also fitted with two Bandak Mk-15B Lightweight taut wires (LWTW), as seen in Figure 10.14.1, located on the starboard side of the vessel, at Frame 78. The Taut Wire is rated for operating in up to 300m water depth.

Figure 10.14.1 Light Weight Taut Wire, Courtesy: Kongsberg Maritime

10.14.2 The LWTW consists of a clump weight, connecting wire, gimbal head fitted with potentiometers, a winch and a pneumatic cylinder to apply constant tension. The LWTW operates by measuring the wire angle and length. The wire angle is measured by the potentiometers in the gimbal head and wire length by a payout meter on the winch drum. With these measurements the DPC can calculate the vessel position.

10.14.3 The LWTWs require the supplies seen in Table 10.14.3 (below) to operate:

LWTW No. 1	Source	Comments
Compressed air	Control air supply 6-10bar	Constant tension cylinder.
440V	440VAC Swbd. Port	Winch power.
230V	DP UPS 1	Alarm, control and measuring systems.
LWTW No. 2	**Source**	**Comments**
Compressed air	Control air supply 6-10bar	Constant tension cylinder.
440V	440VAC Swbd. Stbd.	Winch power.
230V	DP UPS 3	Alarm, control and measuring systems.

Table 10.14.3 Light Weight Taut Wire Requirements

10.15 Taut Wire Failure Mode

10.15.1 Failure of the 440V switchboard section will prevent the winch from operating causing incorrect data being input to the system and an alarm.

10.15.2 Failure of the 230V ship’s power supply will not affect the operation as it is backed up by DP UPS.

10.15.3 Failure of the compressed air supply will prevent the correct wire tension being maintained and cause inaccurate readings. Failure of the air supply by unintentional closing of the air supply will cause a gradual loss of air pressure and cause an alarm. If the air fails due to a burst pipe the LWTW is lost immediately due to uncontrollable payout of the wire.

10.15.4 Wire angle limitation could be exceeded by the vessel’s movement; this would cause the system to alarm and possibly drag the clump weight on the sea bed, more likely if the sea bed surface is hard.

10.16 DP Control System Power Supply

10.16.1 The vessel is equipped with three 3kVA UPS systems for the DP system and its reference systems. No.1 and 2 UPS are supplied from each side of the 230V switchboard. No.3 UPS is dual supplied from both sides. Failure of 230V power supplies would result in an alarm.

10.16.2 Each UPS provides 230VAC to the DPC, references and peripherals. The present UPS distribution is as shown in table 10.16.2 on the following page:

UPS 1	UPS 2	UPS 3
F1 DPC-1	F1 DPC-2	F1 HiPAP OS-1
F2 K-Pos-1	F2 K-Pos-2	F2 HiPAP Transceiver-1
F3 Alarm Printer	F3 DGPS-1 Power	F3 HMS Pressure Sensor
F4 DGPS-2 Power & Spotbeam Demodulator / Serial splitter	F4 DGPS-1 Inmarsat Demodulator / Serial splitter	F4 LTW-2 Power
F5 LTW-1 Power	F5 HiPAP OS-2	F5 Gyro-3
F6 Spare	F6 HiPAP Transceiver-2	F6 Wind Display -3
F7 Spare	F7 Gyro-2	F7 HMS 100
F8 Fanbeam Power	F8 Wind Display -2	F8 Spare
F9 Fanbeam Display	F9 Spare	F9 Spare
F10 Gyro-1	F10 Hardcopy Printer	F10 Spare
F11 Wind Display 1	F11 Spare	F11 Spare
F12 DP Alert System	F12 Spare	F12 DP Alert System

Table 10.16.2 DP UPS Consumers

10.17 cJoy and cWing Controls

10.17.1 The vessel is equipped with a cJoy system, which consists of its dedicated control panel Cc1 (located on the after Bridge), complete with a micro-processer RCU 501. This system is connected to the data networks and can be operated independently from other Operating Stations. The cJoy is provided only with Auto Heading control.

10.17.2 The Cc1 panel has separate inputs from the thrusters, wind sensor-1, and Gyro-3.

10.17.3 To activate the cJoy the DP selector switch at the DPOS must be switched accordingly, and then control taken on the cJoy station.

10.17.4 The vessel is also equipped with a cWing control unit, which can be connected by multi-pin plug to the wing controls. This system uses the Cc1 control panel.

10.17.5 The system is powered by 110VAC from the 110V Bridge Services Panel, which is normally supplied from the port switchboard or on failure, from the ESB.

10.17.6 Failure of the Gyro input will render auto heading control impossible.

10.18 DP Failure Modes

10.18.1 DP Operator Station Failure Modes

Failure Mode	Cause(s)	Probability	Local Effect	Final Effect	Criticality	Remarks
Loss of OS.	Power failure. Fuse failure. Short Circuit. Computer failure.	Low	Alarm for loss of DP OS.	Control can be taken over by DPO on remaining healthy OS. No loss of position.	Minor	If total loss of both OS the DPO to revert to cJoy or manual control.
Loss of 230V main power supply.	Power failure. Fuse failure. Short Circuit.	Low	Alarm on DP.	System switches to UPS power for minimum of 30 minutes. No loss of position.	Minor	
Loss of one DPC Power Supply to RCU501.	Power failure. Fuse failure. Short Circuit.	Low	Alarm on DP.	Other PSU will take additional load.	Minor	
Loss of both DPC Power Supplies to RCU501.	Power failure. Fuse failure. Short Circuit.	Low	Alarm on DP.	All consumers connected to the affected controller will be lost. System changes over to other controller.	Minor	All equipment supplied from alternative system will remain in use.
Failure of network A or B	Open circuit. Short circuit.	Low	Alarm on DP.	Operation continues on alternative network.	Minor	
UPS Battery failure.	Battery failure.	Low	Alarm on DP.	None, as system has main power supply.	Minor	Battery condition should be regularly monitored.
Loss of UPS.	Internal failure.	Low	Alarm on DP.	All consumers connected to the affected UPS will be lost. No loss of position. Loss of DP2 class.	Medium	In case fault is with UPS, can be manually bypassed to Mains.

10.8.2 DP Sensor Failure Modes

Failure Mode	Cause(s)	Probability	Local Effect	Final Effect	Criticality	Remarks
Wind Sensor 1.	Power failure. Mechanical failure. Short circuit. Icing.	Low	Alarm on DP.	System switches to healthy wind sensor. No loss of position.	Minor	All wind sensors need to be enabled to ensure voting.
Wind Sensor 2	Power failure. Mechanical failure. Short circuit. Icing.	Low	Alarm on DP.	System switches to healthy wind sensor. No loss of position.	Minor	All wind sensors need to be enabled to ensure voting.
Wind Sensor 3	Power failure. Mechanical failure. Short circuit. Icing.	Low	Alarm on DP.	System switches to healthy wind sensor. No loss of position.	Minor	All wind sensors need to be enabled to ensure voting.
Gyro failure 1	Power failure. Mechanical failure. Short circuit.	Low	Alarm on DP. HiPAP 1 deselected from DP.	System switches to healthy gyro. HiPAP 1 lost.	Minor	All gyros need to be enabled to ensure voting. DPO can reselect healthy gyro to HiPaP.
Gyro failure 2	Power failure. Mechanical failure. Short circuit.	Low	Alarm on DP. HiPAP 2 deselected from DP.	System switches to healthy gyro. HiPAP 2 lost.	Minor	All gyros need to be enabled to ensure voting. DPO can reselect healthy gyro to HiPaP.
Gyro failure 3	Power failure. Mechanical failure. Short circuit.	Low	Alarm on DP.	System switches to healthy gyro.	Minor	All gyros need to be enabled to ensure voting.

10.8.3 DP Sensor Failure Modes (continued)

Failure Mode	Cause(s)	Probability	Local Effect	Final Effect	Criticality	Remarks
MRU failure 1	Power failure. Mechanical failure. Short circuit.	Low	Alarm on DP. Possibly HiPAP deselected from DP.	System switches to healthy MRU. HiPAP 1 or 2 may be lost.	Minor	DPO selects operational MRUin HiPaP. HiPaP 500 requires MRU1 for heave.
MRU failure 2	Power failure. Mechanical failure. Short circuit.	Low	Alarm on DP. Possibly HiPAP deselected from DP.	System switches to healthy MRU. HiPAP 1 or 2 may be lost.	Minor	DPO selects operational MRU in HiPaP.
MRU failure 3	Power failure. Mechanical failure. Short circuit.	Low	Alarm on DP.	System switches to healthy MRU.	Minor	
DGPS failure 1	Weak signal due to shielding or out of range.	Low	Alarm on DP.	System switches to healthy DGPS.	Minor	No effect on station keeping if weighting correct.
DGPS failure 2	Weak signal due to shielding or out of range.	Low	Alarm on DP.	System switches to healthy DGPS.	Minor	No effect on station keeping if weighting correct.
HiPAP failure 1	Gyro 1 failure. MRU 1 failure. DGPS 1 failure. Transceiver or responder faults. Noise from propeller wash.	Low	Alarm on DP.	Vessel continues to operate on other reference systems.	Minor	No effect on station keeping if weighting correct.
HiPAP failure 2	Gyro 2 failure. MRU 2 failure. DGPS 2 failure. Transceiver or responder faults. Noise from propeller wash.	Low	Alarm on DP.	Vessel continues to operate on other reference systems.	Minor	No effect on station keeping if weighting correct.

10.8.3 DP Sensor Failure Modes (continued)

Failure Mode	Cause(s)	Probability	Local Effect	Final Effect	Criticality	Remarks
LWTW Failure 1	Main power supply or compressed air failure.	Low	Alarm on D.	Vessel continues to operate on other reference systems.	Minor	No effect on station keeping if weighting correct.
LWTW Failure 2	Main power supply or compressed air failure.	Low	Alarm on DP.	Vessel continues to operate on other reference systems.	Minor	No effect on station keeping if weighting correct.
Fanbeam Failure	Power failure Scanner failure Poor visibility Encoder or serial link	Low	Alarm on DP.	Vessel continues to operate on other reference systems.	Minor	No effect on station keeping if weighting correct.

Appendix 1

Kongsberg Maritime Capability Analysis of Adams Challenge

KONGSBERG

DP Capability Analysis

Balenciaga H 400

Project:	2926215
Product	Kpos
Synopsis:	This document contains a DP capability analysis for Balenciaga H 400. The Kongsberg Maritime computer program StatCap has been used for the simulations.

Document number:	**1080176**	*Revision:*	B
Customer doc number:		*Document version:*	
Contract number:	2926215	*Number of pages:*	59

Rev.	***Date***	***Reason for issue***	***Made by***	***Checked***	***Approved***
A	26-06-2008	First Issue	EG	EG	EG
B	28-10-2008	Added bus failure cases	JH	VE	EG
C					
D					
E					

Kongsberg Maritime AS

Table of contents

1 ABOUT THIS DOCUMENT

1.1 Document history

Revision	*Description of Change*
A	First Issue
B	Added bus failure cases

1.2 References

References	
Reference 1	*The International Marine Contractors Association* Specification for DP capability plots *IMCA M 140 Rev. 1, June 2000.*
Reference 2	*Det Norske Veritas* Rules for classification of Mobile Offshore Units, Part 6, Chapter 7, *Det Norske Veritas July 1989.*
Reference 3	*Faltinsen, O. M.* Sea Loads on Ships and Offshore Structures *Cambridge University Press 1990.*
Reference 4	*Brix, J. (editor)* Manoeuvring Technical Manual *Seehafen Verlag, 1993.*
Reference 5	*Walderhaug, H.* Skipshydrodynamikk Grunnkurs *Tapir (in Norwegian).*
Reference 6	*OCIMF* Prediction of Wind and Current Loads on VLCCs *Oil Companies International Marine Forum, 2nd Edition – 1994.*

References	
Reference 7	*Lehn, E.* On the propeller race interaction effects *MARINTEK publication P-01.85, September 1985.*
Reference 8	*Lehn, E.* Practical methods for estimation of thrust losses *MARINTEK publication* R-102.80*, October 1990.*
Reference 9	*Lehn, E. and Larsen, K.* Thrusters in extreme condition, part 1. Ventilation and out of water effects *FPS-2000 1.6B, January, 1990.*
Reference 10	*Lehn, E.* Thrusters in extreme condition, part 2. Propeller/hull interaction effects *FPS-2000 1.6B, January, 1990.*
Reference 11	*Svensen, T.* Thruster considerations in the design of DP assisted vessels *NIF, June, 1992.*
Reference 12	*MARIN, Maritime Research Institute Netherlands* Training Course OFFSHORE HYDRODYNAMICS, lecture notes, 1993.
Reference 13	*Norwegian Petroleum Directorate* Regulations relating to loadbearing structures in the petroleum activities *Guidelines relating to loads and load effects etc. (Unofficial translation), 1998.*
Reference 14	Model for a doubly peaked wave spectrum *SINTEF STF22 A96204, 1996.*
Reference 15	General Arrangement *Drawing 1091343, 2008-Oktober-27.*
Reference 16	Thruster size and location input *Single line diagram, Doc number 1054122.*

1.3 Definitions / Abbreviations

DNV	Det Norske Veritas
DP	Dynamic Positioning
ERN	Environmental Regularity Numbers
IMCA	The International Marine Contractors Association
NPD	Norwegian Petroleum Directorate
OCIMF	Oil Companies International Marine Forum
StatCap	Kongsberg Maritime Static DP Capability computer program
VLCC	Very Large Crude Carrier

1.4 Disclaimer

Kongsberg Maritime AS has made its best effort to ensure that this DP capability analysis is correct and reflects the vessel’s actual performance and capability most likely to be attained during operation. The DP capability analysis is however a simulation analysis only and must not be considered as a guarantee of actual performance and capability. The DP capability analysis is based on calculations, expectations, estimates and input data subject to uncertainties, which may influence on the correctness, accuracy, reliability and completeness of the results herein. The correctness of the DP capability analysis is inextricably related to the correctness of input data received by Kongsberg Maritime AS from client, thruster vendors and others, and the client shall be fully responsible for the correctness and accuracy of the input data made available to Kongsberg Maritime AS prior to the execution of the DP capability analysis. Any change or alteration made to the input data such as vessel design, vessel equipment, vessel operational draught, wind area projections, thruster data or configuration, area of operation or any other input data on which the analysis is based may alter the results hereof and render this analysis inapplicable to the new context. Kongsberg Maritime AS can make no representation or warranty, expressed or implied as to the accuracy, reliability or completeness of this DP capability analysis, and Kongsberg Maritime AS, its directors, officers or employees shall have no liability resulting from the use of this DP capability analysis regardless of its objective.

2 SUMMARY AND CONCLUSIONS

This report contains a DP capability analysis for Balenciaga H 400 in DNV (ERN) conditions. The analysis has been based upon the information given in Reference 15 and Reference 16. The Kongsberg Maritime computer program StatCap has been used for the simulations.

The simulation case definitions are given in Table 1. T1 denotes thruster number 1, T2 thruster number 2 and so on. For details regarding thruster layout, see Figure 2.

Case no.	*Current speed [kts]*	*Thrusters active*	*Case description*
1	1.5	T1-T5	T1-T5 ERN
2	1.5	T1-T3, T5	T1-T3, T5 Min eff. Single Thr. T4 Lost
3	1.5	T1-T2, T4-T5	T1-T2,T4-T5Max eff.Single Thr. T3 Lost
4	1.5	T2-T3, T5	Bus A Failure T1, T4 Lost
5	1.5	T1, T3-T4	Bus B Failure T2, T5 Lost

Table 1: Simulation case definitions.

The simulation results are summarised in Table 2 showing the limiting weather conditions at the most unfavourable wind directions.

Case no.	*Wind speed [kts]*	*Wind direction [deg]*	*Hs [m]*	*Tz [sec]*	*Current speed [kts]*
1	58.6	90.0	8.9	11.7	1.5
2	49.8	60.0	7.4	11.0	1.5
3	44.5	70.0	6.5	10.5	1.5
4	38.2	60.0	5.5	10.0	1.5
5	38.7	300.0	5.6	10.1	1.5

Table 2: Limiting conditions at most unfavourable wind directions.

Note that a certain amount of dynamic load allowance is included in the simulations. The dynamic allowance is the ‘spare’ thrust required to compensate for the dynamic effects of the wind and wave drift loads, see section 4.4.

DNV ERN results for case 1: ERN (99, 99, 99). These are subject to DNV approval. The minimum effect of single-thruster failure occurs when thruster 4 is lost and the maximum effect of single-thruster failure occurs when thruster 3 is lost.

The nominal bollard thrust is calculated from power according to Reference 1. In normal operating conditions the thrust is reduced due to current, waves and the presence of the hull. Approximations for the thrust losses are taken into account in the simulations, see section 5.2.

3 COORDINATE SYSTEM

The coordinate system used is the orthogonal right-handed system shown in Figure 1 with the positive z-axis pointing downwards. The origin of the coordinate system can be offset a longitudinal distance x_0 from $L_{pp}/2$.

The directions of the wind, waves and current are defined by means of coming-from directions and are considered positive when turning clockwise, e.g. a wind direction equal to 0 degrees exerts a negative longitudinal force on the vessel.

Unless otherwise stated, the directions of the wind, waves and current are coincident in the analyses.

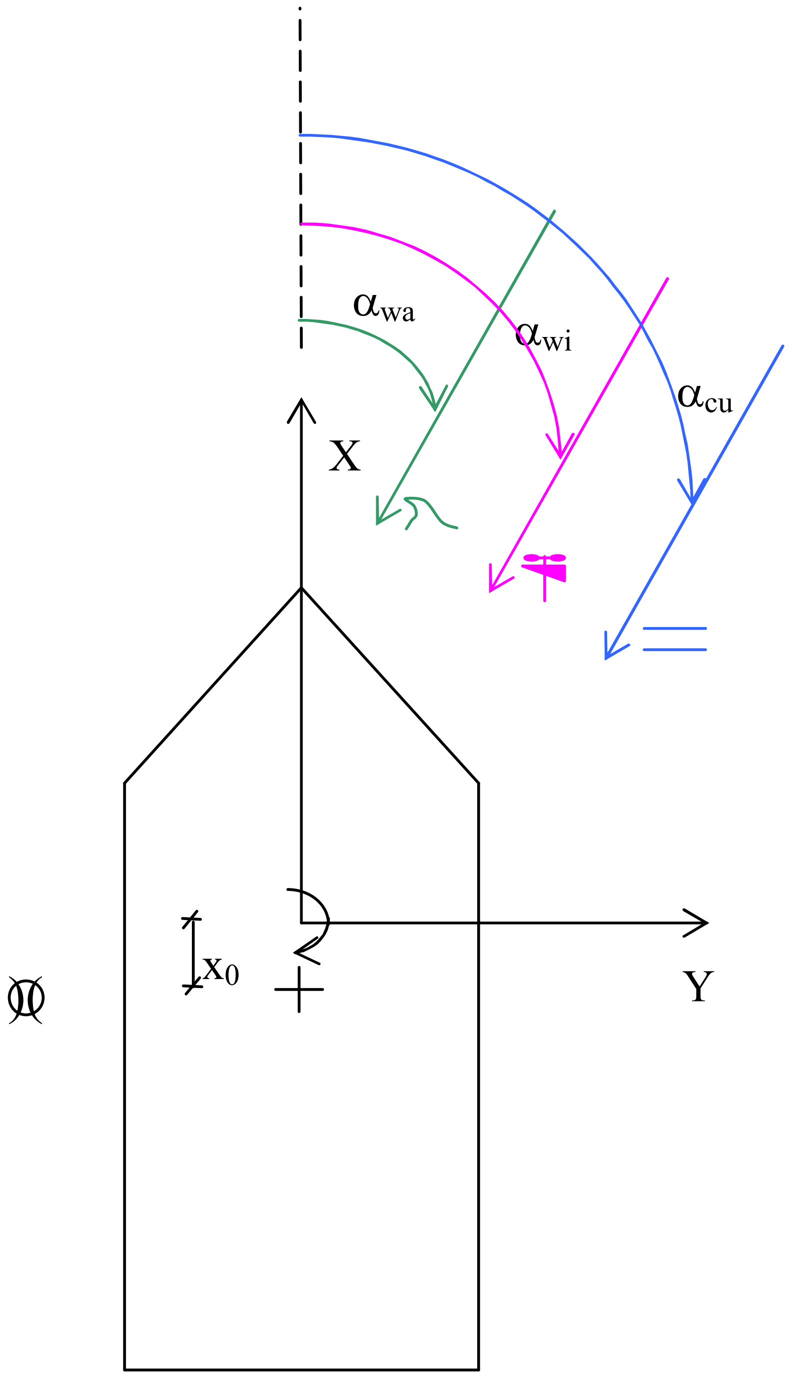


Figure 1: Coordinate system and sign conventions.

4 DP CAPABILITY

4.1 Definition

DP capability defines a DP vessel's station-keeping ability under given environmental and operational conditions.

4.2 Wind Speed Envelopes

DP capability analyses are generally used to establish the maximum weather conditions in which a DP vessel can maintain its position and heading for a proposed thruster configuration. The environmental forces and moments are increased until they are exactly balanced by the maximum available thrust offered by the thruster configuration. Thus, a limiting weather condition is obtained as a combination of a mean wind speed, significant wave height and a sea current speed. Wind, current and waves are normally taken as coming from the same direction. By allowing the environmental components to rotate in steps around the vessel, the results of a DP capability analysis can be presented by means of a limiting mean wind speed for a discrete number of wind angles of attack. The resulting polar plot is often referred to as a DP capability envelope.

4.3 Thrust Utilisation Envelopes

When a design sea state is determined by the client, DP capability can be presented by means of a thrust utilisation envelope instead of a limiting wind speed envelope. The required thrust to maintain position and heading in the design sea state is calculated and compared to the vessel's maximum available thrust. The ratio between the two is plotted as a function of wind direction. A thrust utilisation less than or equal to 100% means that the vessel is able to hold position and heading in the specified design sea state. If the ratio exceeds 100%, the vessel will experience poor positioning performance or drift off.

4.4 Dynamic Allowance

A DP vessel needs a certain amount of 'spare' thrust to compensate for the dynamic behaviour of the wind and wave drift loads. The 'spare' thrust can be included as a given percentage of the wind and wave drift loads or it can be calculated from the spectral densities of the wind and wave drift loads and the controller's restoring and damping characteristics. The manner in which the dynamic allowance is included is stated on each capability envelope sheet.

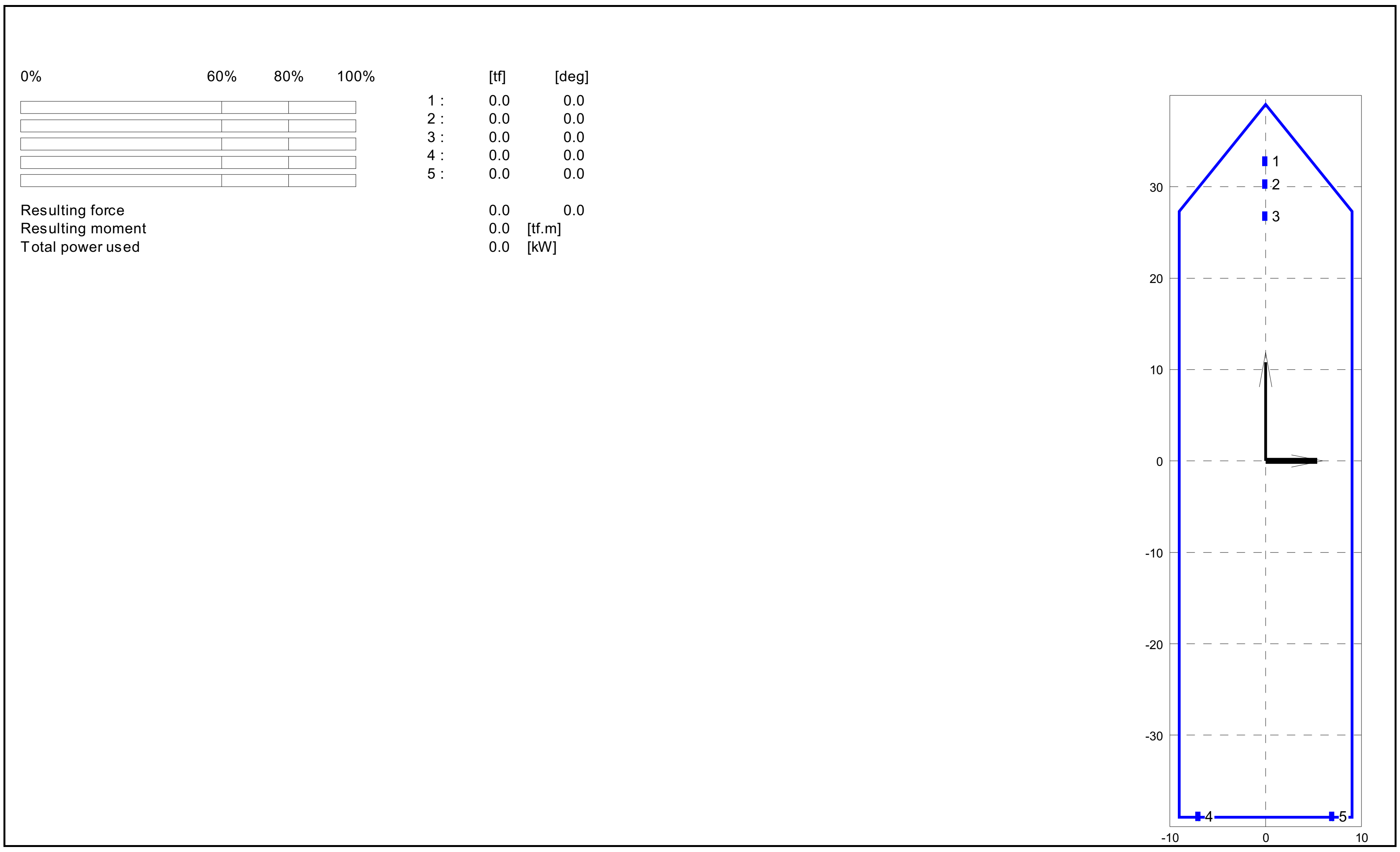
5 INPUT DATA

5.1 Main Particulars

The vessel main particulars are listed on each capability envelope sheet.

5.2 Thruster Data

General thruster data such as locations on the hull and capacities, see Reference 16, is listed on each capability envelope sheet.



	[tf]	[deg]
1 :	0.0	0.0
2 :	0.0	0.0
3 :	0.0	0.0
4 :	0.0	0.0
5 :	0.0	0.0
Resulting force	0.0	0.0
Resulting moment	0.0	[tf.m]
Total power used	0.0	[kW]

Figure 2: Thruster layout.

5.3 Wind Load Coefficients

StatCap offers several methods for obtaining wind load coefficients. Each of the methods is listed in Table 3 together with a short description. The method used is indicated on the capability envelope sheets. The wind affected areas are calculated on the basis of Reference 15.

Method	*Applicable to*	*Description*
Blendermann	Mono-hulls	The method describes wind loading functions which can be combined with the vessel's wind resistance in head, stern and beam wind. Typical wind resistance for a number of relevant offshore ship types is also described, see Reference 4.
Hughes	Mono-hulls	The method describes a wind loading function which can be combined with the vessel's wind resistance. Typical wind resistance for a number of merchant ship types is also described, see Reference 5.
Database scaling	Mono-hulls/semi-submersibles	The wind load coefficients are obtained through scaling of data for a similar vessel in the Kongsberg Maritime database. The coefficients are scaled with respect to the wind-affected areas of the frontal and lateral projections.
External file input	Mono-hulls/semi-submersibles	Specific wind load coefficients, supplied by the client, are read and used by StatCap.

Table 3: Methods for obtaining wind load coefficients in StatCap.

Last Modified	:	2008-10-28 11.17
Vessel Name	:	Balenciaga H 400
File Ref.	:	Foot_2963_RevA.scp
Vessel type	:	Diving vessel
Area of frontal projection	:	334.2 m² (20 points)
Area of lateral projection	:	1039.8 m² (97 points)
Mean height of lateral projection	:	12.1 m
Dist. to centroid of lateral projection	:	7.8 m

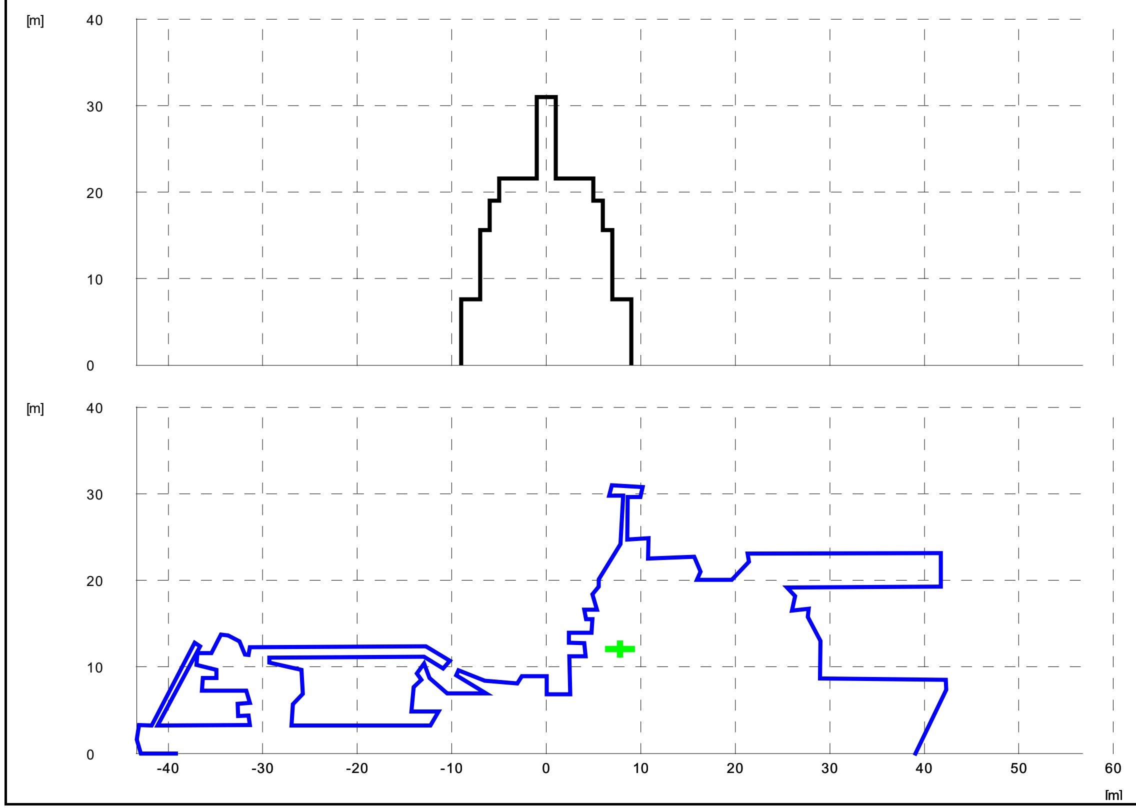


Figure 3: Wind area projections.

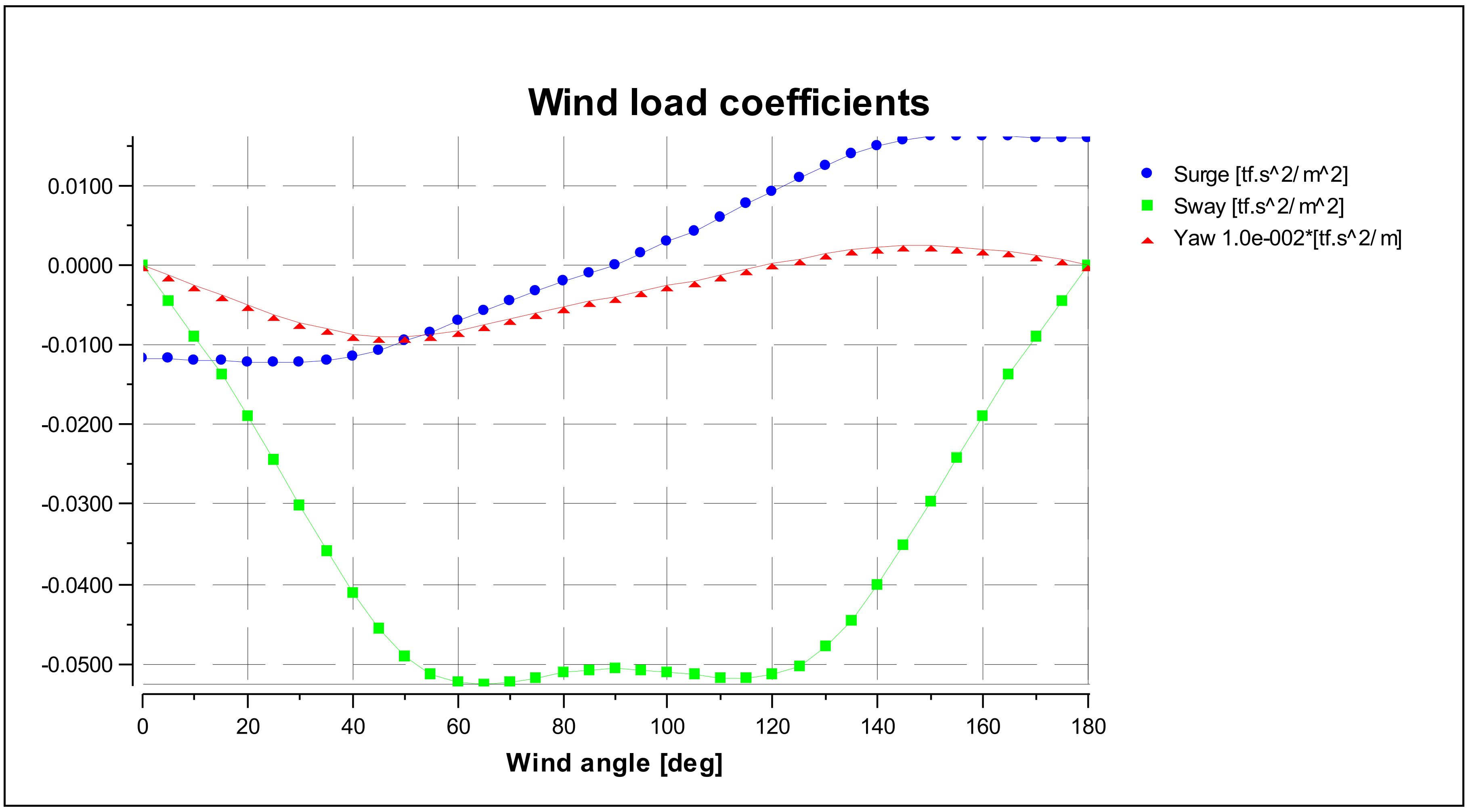


Figure 4: Wind load coefficients.

5.4 Current Load Coefficients

StatCap offers several methods for obtaining current load coefficients. Each of the methods is listed in Table 4 along with a short description. The method used is indicated on the capability envelope sheets.

Method	*Applicable to*	*Description*
Modified strip-theory	Mono-hulls	A simplified strip-theory approach is applied in order to calculate the transverse and yawing moment current load coefficients. For a description of the strip-theory approach, see Reference 3. The longitudinal load coefficient is calculated using the method described in Reference 3. However, the longitudinal coefficient has been adjusted for improved match against a number of model test results in the Kongsberg Maritime database.
OCIMF	VLCCs	The current load coefficients are calculated based on the results presented in Reference 6.

Database scaling	Mono-hulls/semi-submersibles	The current load coefficients are obtained through scaling of data for a similar vessel in the Kongsberg Maritime database. The coefficients are scaled with respect to length and draught or displacement.
External file input	Mono-hulls/semi-submersibles	Specific current load coefficients, supplied by the client, are read and used by StatCap.

Table 4: Methods for obtaining current load coefficients in StatCap.

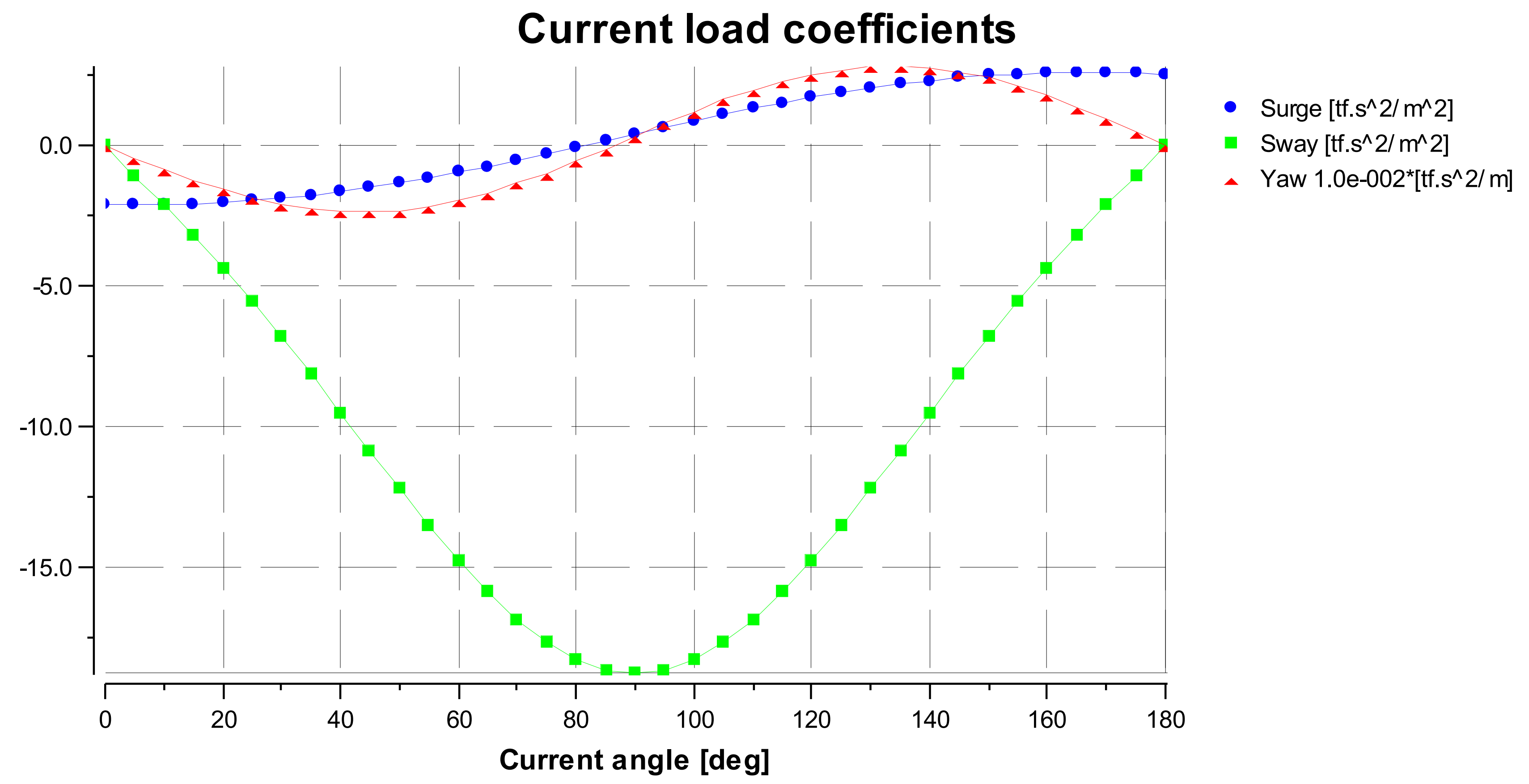


Figure 5: Current load coefficients.

5.5 Wave-Drift Load Coefficients

StatCap offers two methods to arrive at wave-drift load coefficients, see Table 5. The method used is indicated on the capability envelope sheets.

Method	*Applicable to*	*Description*
Database scaling	Mono-hulls/semi-submersibles	The wave-drift load coefficients are obtained through scaling of data for a similar vessel in the Kongsberg Maritime database. The coefficients are scaled with respect to length and breadth, length or displacement.
External file input	Mono-hulls/semi-submersibles	Specific wave-drift load coefficients, supplied by the client, are read up and used by StatCap.

Table 5: Methods for obtaining wave-drift load coefficients.

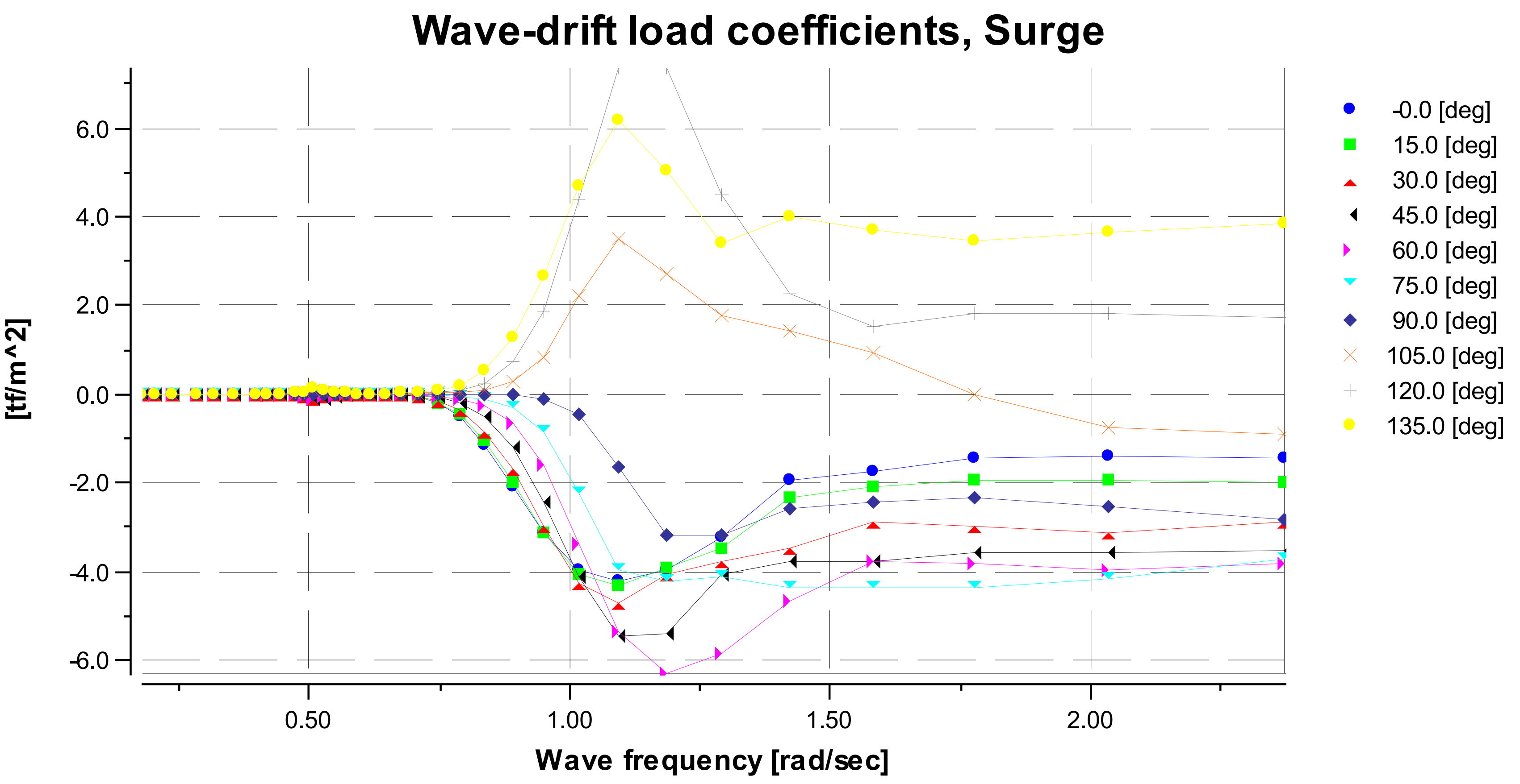


Figure 6: Wave-drift load coefficients for surge.

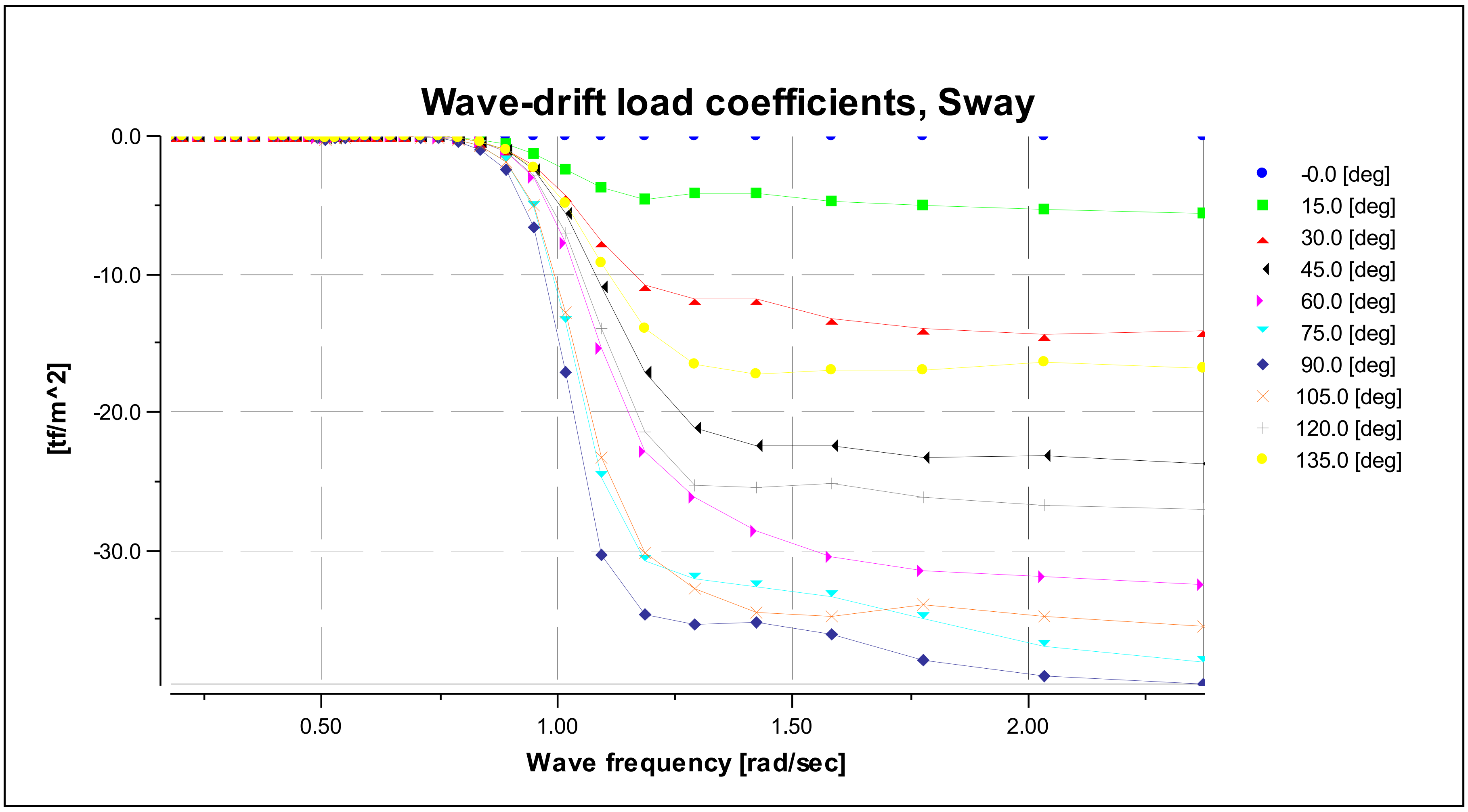


Figure 7: Wave-drift load coefficients for sway.

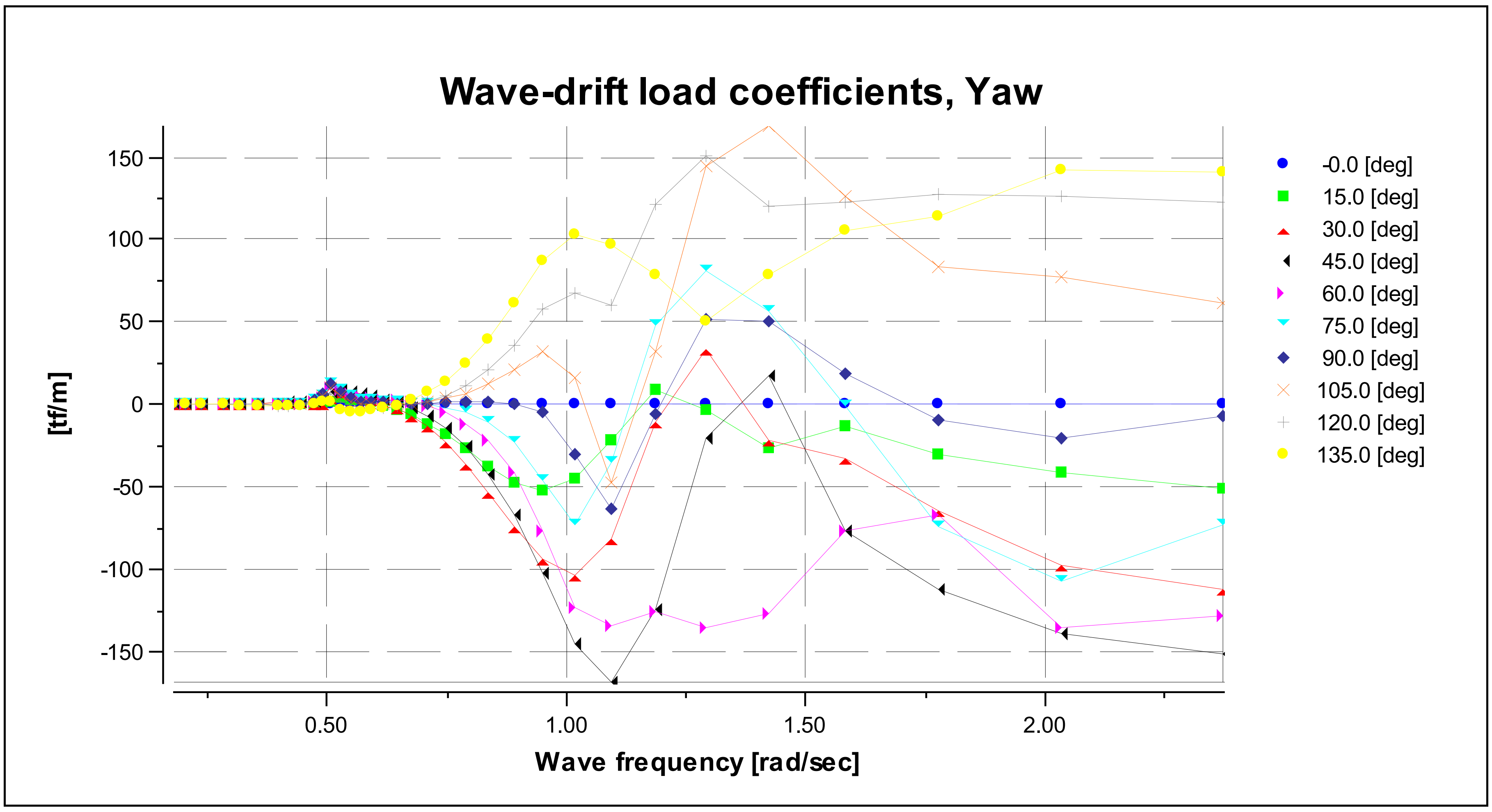


Figure 8: Wave-drift load coefficients for yaw.

5.6 Wind Speed and Wave Height Relationship

Several wind and wave spectrum types are available in StatCap. Each of the wave spectrum types is listed in Table 6 together with a short description. The wind spectrum type selected does not affect the wind loads as such, but has an influence on the dynamic allowance, see section 4.4. For a description of the NPD spectrum, used as default wind spectrum in StatCap, see Reference 13. For descriptions of the other wind spectrum types refer to the literature, e.g. see Reference 12. The spectrum types used in each case are indicated on the capability envelope sheets.

Wave spectrum	*Applicable to*	*Description*
Pierson-Moskowitz	North Atlantic	Wave spectrum for fully developed sea and open sea conditions, see Reference 3.
JONSWAP	North Sea	Joint North Sea Wave Project, see Reference 3, valid for sea not fully developed (the fetch has limited length).
Doubly-Peaked	Norwegian Sea	Wave spectrum for wind-generated sea and swell. A modified JONSWAP model is used for both peaks, see Reference 14.

Table 6: Wave spectrum types.

The relationship between wind speed and wave height used in the analyses is defined in Reference 2.

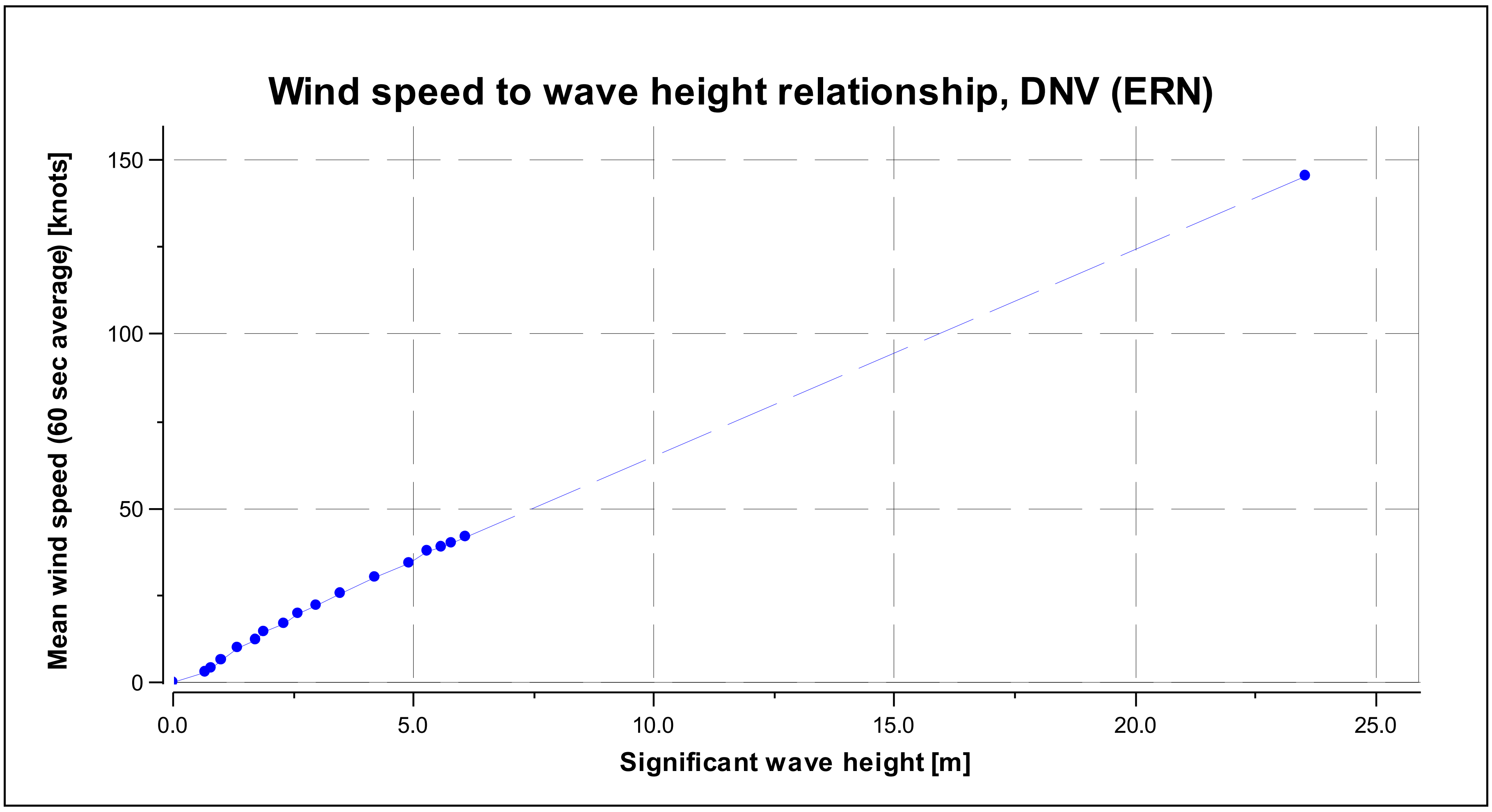
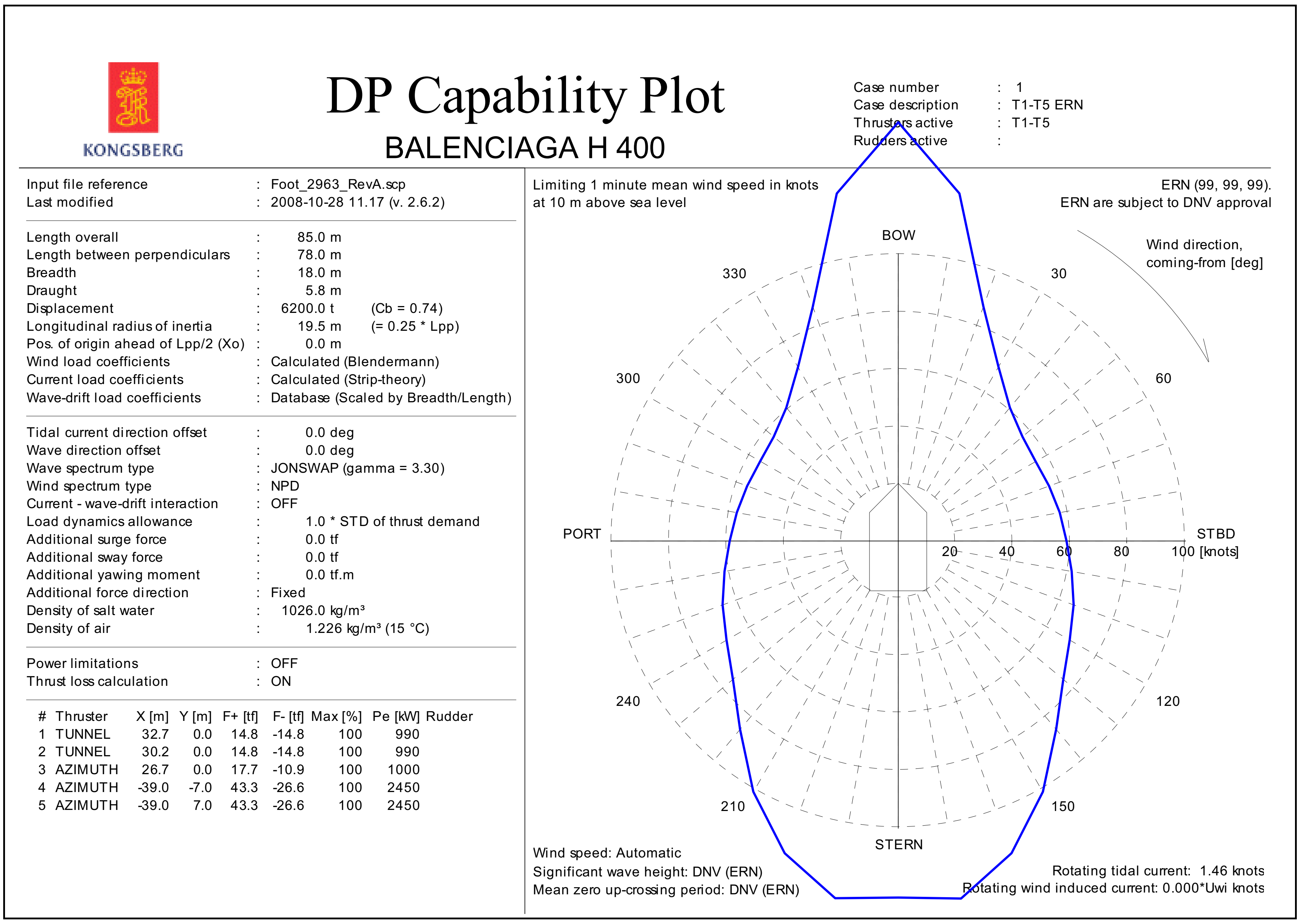


Figure 9: Wind speed to wave height relationship.

6 RESULTS

6.1 Case 1



DP Capability Plot

BALENCIAGA H 400

Case number : 1
Case description : T1-T5 ERN
Thrusters active : T1-T5
Rudders active :

Input file reference : Foot_2963_RevA.scp
Last modified : 2008-10-28 11.17 (v. 2.6.2)

Length overall : 85.0 m
Length between perpendiculars : 78.0 m
Breadth : 18.0 m
Draught : 5.8 m
Displacement : 6200.0 t (Cb = 0.74)
Longitudinal radius of inertia : 19.5 m (= 0.25 * Lpp)
Pos. of origin ahead of Lpp/2 (Xo) : 0.0 m
Wind load coefficients : Calculated (Blendermann)
Current load coefficients : Calculated (Strip-theory)
Wave-drift load coefficients : Database (Scaled by Breadth/Length)

Tidal current direction offset : 0.0 deg
Wave direction offset : 0.0 deg
Wave spectrum type : JONSWAP (gamma = 3.30)
Wind spectrum type : NPD
Current - wave-drift interaction : OFF
Load dynamics allowance : 1.0 * STD of thrust demand
Additional surge force : 0.0 tf
Additional sway force : 0.0 tf
Additional yawing moment : 0.0 tf.m
Additional force direction : Fixed
Density of salt water : 1026.0 kg/m³
Density of air : 1.226 kg/m³ (15 °C)

Power limitations : OFF
Thrust loss calculation : ON

#	Thruster	X [m]	Y [m]	F+ [tf]	F- [tf]	Max [%]	Pe [kW]	Rudder
1	TUNNEL	32.7	0.0	14.8	-14.8	100	990	
2	TUNNEL	30.2	0.0	14.8	-14.8	100	990	
3	AZIMUTH	26.7	0.0	17.7	-10.9	100	1000	
4	AZIMUTH	-39.0	-7.0	43.3	-26.6	100	2450	
5	AZIMUTH	-39.0	7.0	43.3	-26.6	100	2450	

Limiting 1 minute mean wind speed in knots
at 10 m above sea level

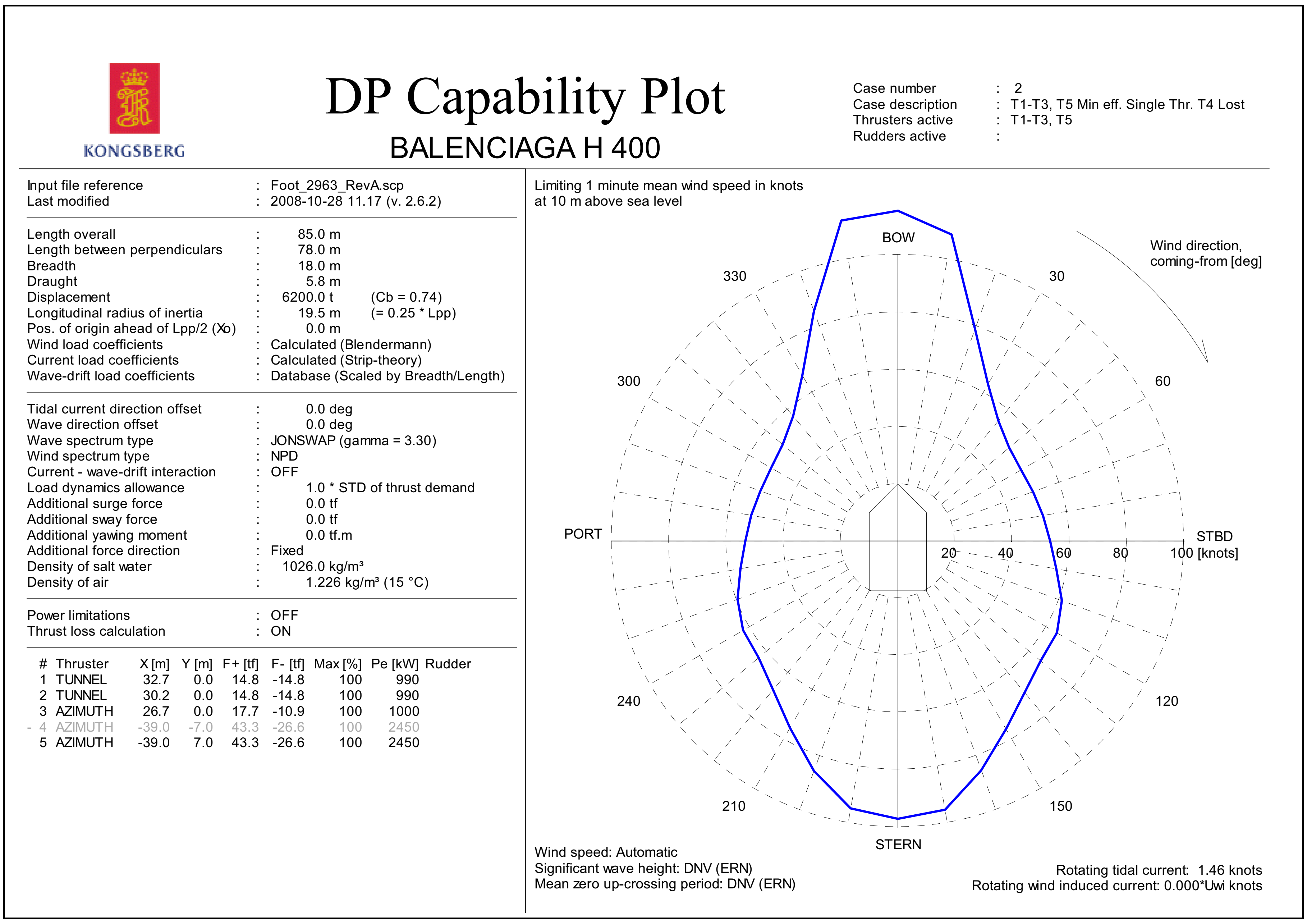
ERN (99, 99, 99).
ERN are subject to DNV approval

Wind speed: Automatic
Significant wave height: DNV (ERN)
Mean zero up-crossing period: DNV (ERN)

Rotating tidal current: 1.46 knots
Rotating wind induced current: 0.000*Uwi knots

Figure 10: DP capability envelope for case 1.

6.2 Case 2



KONGSBERG

DP Capability Plot

BALENCIAGA H 400

Case number : 2
Case description : T1-T3, T5 Min eff. Single Thr. T4 Lost
Thrusters active : T1-T3, T5
Rudders active :

Input file reference : Foot_2963_RevA.scp
Last modified : 2008-10-28 11.17 (v. 2.6.2)

Length overall : 85.0 m
Length between perpendiculars : 78.0 m
Breadth : 18.0 m
Draught : 5.8 m
Displacement : 6200.0 t (Cb = 0.74)
Longitudinal radius of inertia : 19.5 m (= 0.25 * Lpp)
Pos. of origin ahead of Lpp/2 (Xo) : 0.0 m
Wind load coefficients : Calculated (Blendermann)
Current load coefficients : Calculated (Strip-theory)
Wave-drift load coefficients : Database (Scaled by Breadth/Length)

Tidal current direction offset : 0.0 deg
Wave direction offset : 0.0 deg
Wave spectrum type : JONSWAP (gamma = 3.30)
Wind spectrum type : NPD
Current - wave-drift interaction : OFF
Load dynamics allowance : 1.0 * STD of thrust demand
Additional surge force : 0.0 tf
Additional sway force : 0.0 tf
Additional yawing moment : 0.0 tf.m
Additional force direction : Fixed
Density of salt water : 1026.0 kg/m³
Density of air : 1.226 kg/m³ (15 °C)

Power limitations : OFF
Thrust loss calculation : ON

#	Thruster	X [m]	Y [m]	F+ [tf]	F- [tf]	Max [%]	Pe [kW]	Rudder
1	TUNNEL	32.7	0.0	14.8	-14.8	100	990	
2	TUNNEL	30.2	0.0	14.8	-14.8	100	990	
3	AZIMUTH	26.7	0.0	17.7	-10.9	100	1000	
- 4	AZIMUTH	-39.0	-7.0	43.3	-26.6	100	2450	
5	AZIMUTH	-39.0	7.0	43.3	-26.6	100	2450	

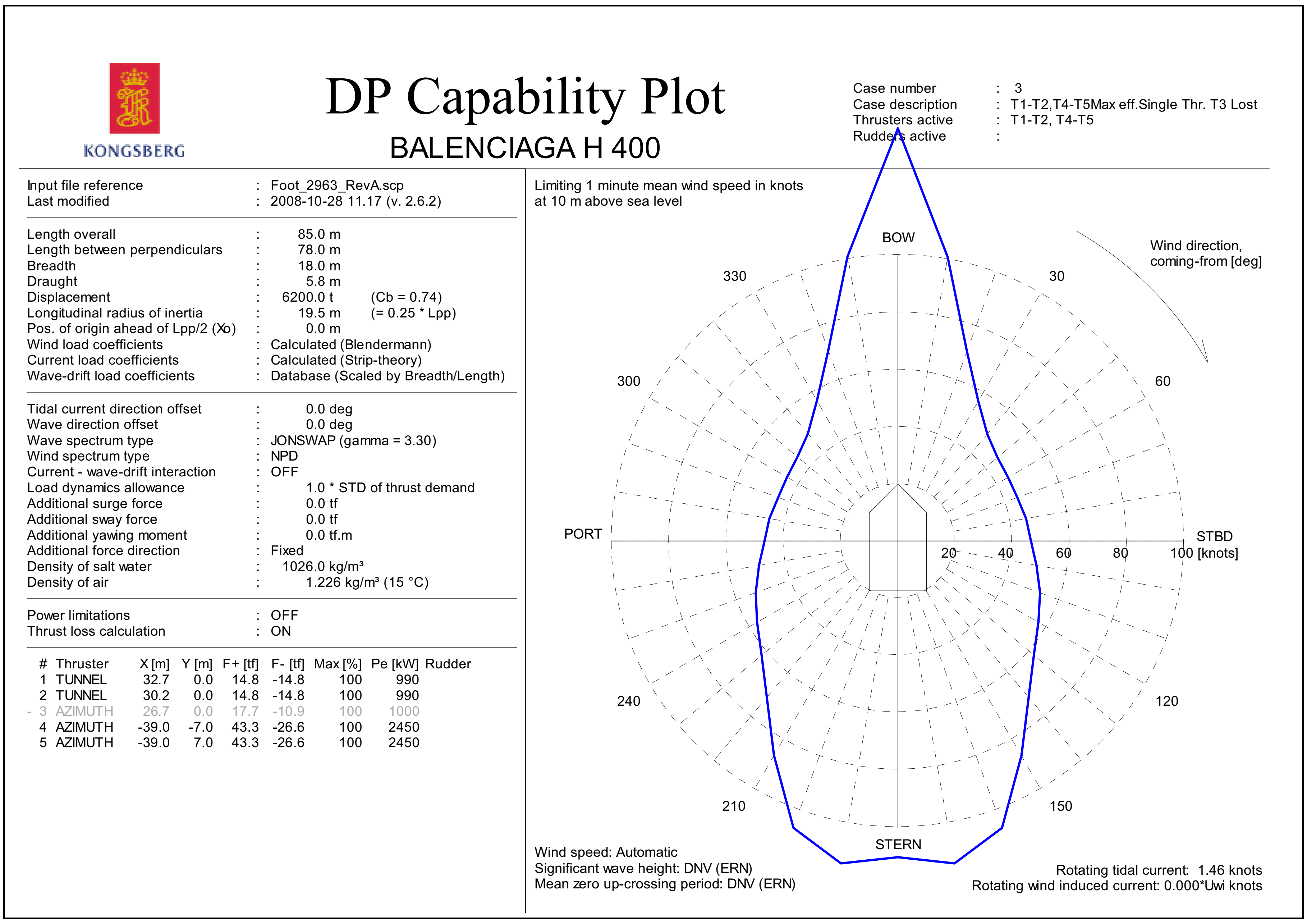
Limiting 1 minute mean wind speed in knots
at 10 m above sea level

Wind speed: Automatic
Significant wave height: DNV (ERN)
Mean zero up-crossing period: DNV (ERN)

Rotating tidal current: 1.46 knots
Rotating wind induced current: 0.000*Uwi knots

Figure 11: DP capability envelope for case 2.

6.3 Case 3



KONGSBERG

DP Capability Plot

BALENCIAGA H 400

Case number : 3
Case description : T1-T2,T4-T5Max eff.Single Thr. T3 Lost
Thrusters active : T1-T2, T4-T5
Rudders active :

Input file reference : Foot_2963_RevA.scp
Last modified : 2008-10-28 11.17 (v. 2.6.2)

Length overall : 85.0 m
Length between perpendiculars : 78.0 m
Breadth : 18.0 m
Draught : 5.8 m
Displacement : 6200.0 t (Cb = 0.74)
Longitudinal radius of inertia : 19.5 m (= 0.25 * Lpp)
Pos. of origin ahead of Lpp/2 (Xo) : 0.0 m
Wind load coefficients : Calculated (Blendermann)
Current load coefficients : Calculated (Strip-theory)
Wave-drift load coefficients : Database (Scaled by Breadth/Length)

Tidal current direction offset : 0.0 deg
Wave direction offset : 0.0 deg
Wave spectrum type : JONSWAP (gamma = 3.30)
Wind spectrum type : NPD
Current - wave-drift interaction : OFF
Load dynamics allowance : 1.0 * STD of thrust demand
Additional surge force : 0.0 tf
Additional sway force : 0.0 tf
Additional yawing moment : 0.0 tf.m
Additional force direction : Fixed
Density of salt water : 1026.0 kg/m^3
Density of air : 1.226 kg/m^3 (15 °C)

Power limitations : OFF
Thrust loss calculation : ON

	#	Thruster	X [m]	Y [m]	F+ [tf]	F- [tf]	Max [%]	Pe [kW]	Rudder
	1	TUNNEL	32.7	0.0	14.8	-14.8	100	990	
	2	TUNNEL	30.2	0.0	14.8	-14.8	100	990	
-	3	AZIMUTH	26.7	0.0	17.7	-10.9	100	1000	
	4	AZIMUTH	-39.0	-7.0	43.3	-26.6	100	2450	
	5	AZIMUTH	-39.0	7.0	43.3	-26.6	100	2450	

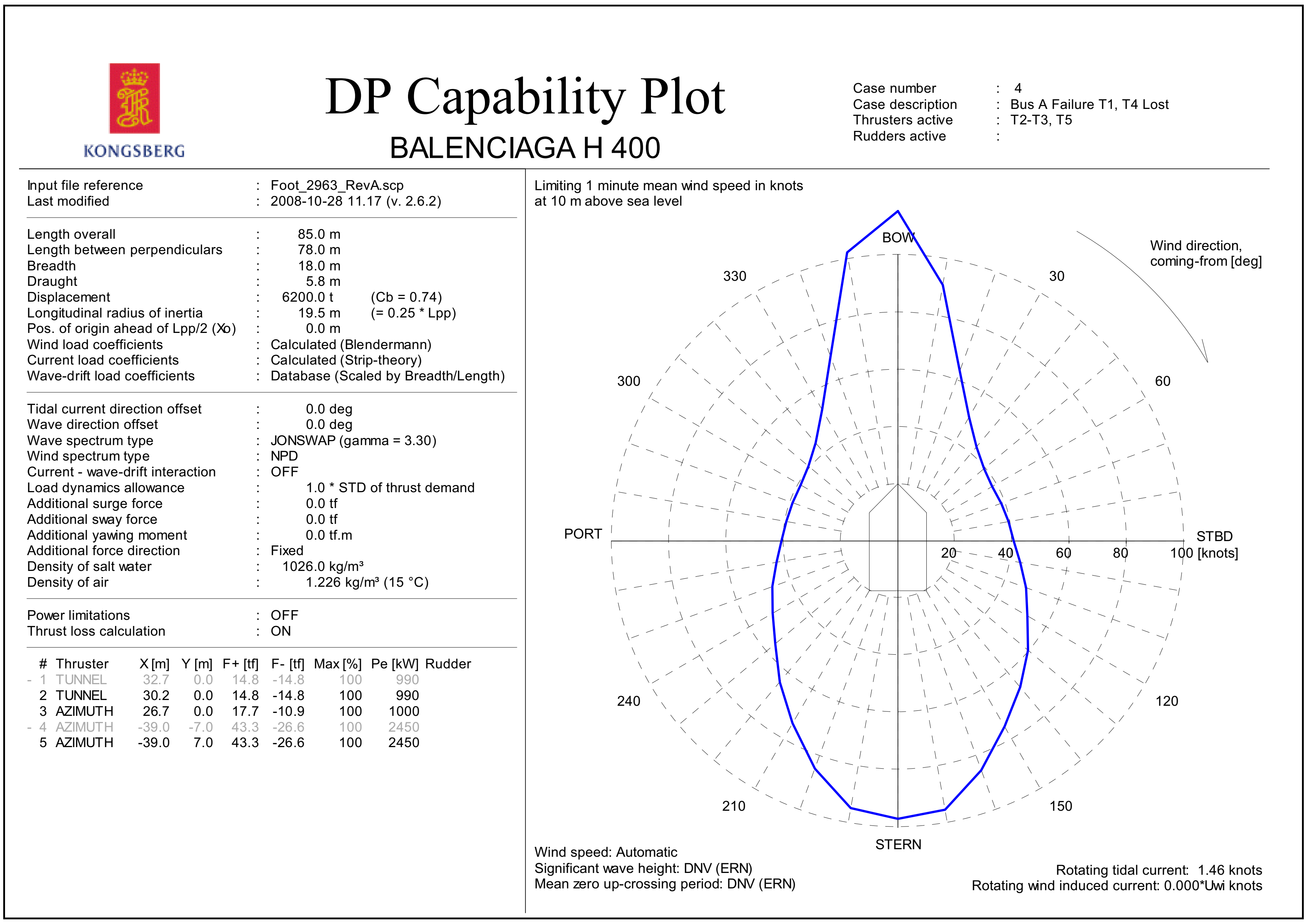
Limiting 1 minute mean wind speed in knots
at 10 m above sea level

Wind speed: Automatic
Significant wave height: DNV (ERN)
Mean zero up-crossing period: DNV (ERN)

Rotating tidal current: 1.46 knots
Rotating wind induced current: 0.000*Uwi knots

Figure 12: DP capability envelope for case 3.

6.4 Case 4



KONGSBERG

DP Capability Plot

BALENCIAGA H 400

Case number : 4
Case description : Bus A Failure T1, T4 Lost
Thrusters active : T2-T3, T5
Rudders active :

Input file reference : Foot_2963_RevA.scp
Last modified : 2008-10-28 11.17 (v. 2.6.2)

Length overall : 85.0 m
Length between perpendiculars : 78.0 m
Breadth : 18.0 m
Draught : 5.8 m
Displacement : 6200.0 t (Cb = 0.74)
Longitudinal radius of inertia : 19.5 m (= 0.25 * Lpp)
Pos. of origin ahead of Lpp/2 (Xo) : 0.0 m
Wind load coefficients : Calculated (Blendermann)
Current load coefficients : Calculated (Strip-theory)
Wave-drift load coefficients : Database (Scaled by Breadth/Length)

Tidal current direction offset : 0.0 deg
Wave direction offset : 0.0 deg
Wave spectrum type : JONSWAP (gamma = 3.30)
Wind spectrum type : NPD
Current - wave-drift interaction : OFF
Load dynamics allowance : 1.0 * STD of thrust demand
Additional surge force : 0.0 tf
Additional sway force : 0.0 tf
Additional yawing moment : 0.0 tf.m
Additional force direction : Fixed
Density of salt water : 1026.0 kg/m³
Density of air : 1.226 kg/m³ (15 °C)

Power limitations : OFF
Thrust loss calculation : ON

	#	Thruster	X [m]	Y [m]	F+ [tf]	F- [tf]	Max [%]	Pe [kW]	Rudder
-	1	TUNNEL	32.7	0.0	14.8	-14.8	100	990	
	2	TUNNEL	30.2	0.0	14.8	-14.8	100	990	
	3	AZIMUTH	26.7	0.0	17.7	-10.9	100	1000	
-	4	AZIMUTH	-39.0	-7.0	43.3	-26.6	100	2450	
	5	AZIMUTH	-39.0	7.0	43.3	-26.6	100	2450	

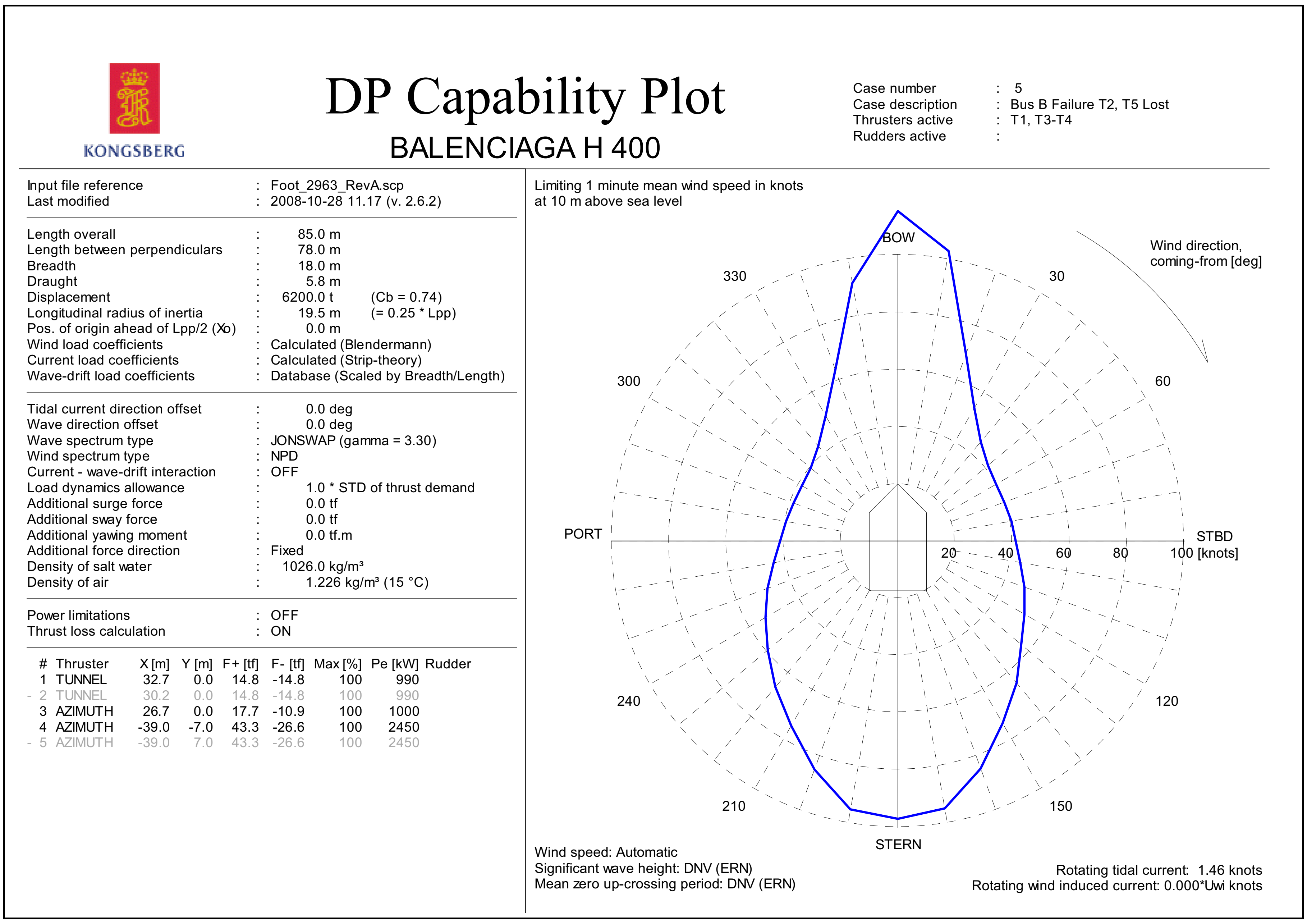
Limiting 1 minute mean wind speed in knots
at 10 m above sea level

Wind speed: Automatic
Significant wave height: DNV (ERN)
Mean zero up-crossing period: DNV (ERN)

Rotating tidal current: 1.46 knots
Rotating wind induced current: 0.000*Uwi knots

Figure 13: DP capability envelope for case 4.

6.5 Case 5



KONGSBERG

DP Capability Plot

BALENCIAGA H 400

Case number : 5
Case description : Bus B Failure T2, T5 Lost
Thrusters active : T1, T3-T4
Rudders active :

Input file reference : Foot_2963_RevA.scp
Last modified : 2008-10-28 11.17 (v. 2.6.2)

Length overall : 85.0 m
Length between perpendiculars : 78.0 m
Breadth : 18.0 m
Draught : 5.8 m
Displacement : 6200.0 t (Cb = 0.74)
Longitudinal radius of inertia : 19.5 m (= 0.25 * Lpp)
Pos. of origin ahead of Lpp/2 (Xo) : 0.0 m
Wind load coefficients : Calculated (Blendermann)
Current load coefficients : Calculated (Strip-theory)
Wave-drift load coefficients : Database (Scaled by Breadth/Length)

Tidal current direction offset : 0.0 deg
Wave direction offset : 0.0 deg
Wave spectrum type : JONSWAP (gamma = 3.30)
Wind spectrum type : NPD
Current - wave-drift interaction : OFF
Load dynamics allowance : 1.0 * STD of thrust demand
Additional surge force : 0.0 tf
Additional sway force : 0.0 tf
Additional yawing moment : 0.0 tf.m
Additional force direction : Fixed
Density of salt water : 1026.0 kg/m³
Density of air : 1.226 kg/m³ (15 °C)

Power limitations : OFF
Thrust loss calculation : ON

	#	Thruster	X [m]	Y [m]	F+ [tf]	F- [tf]	Max [%]	Pe [kW]	Rudder
	1	TUNNEL	32.7	0.0	14.8	-14.8	100	990	
-	2	TUNNEL	30.2	0.0	14.8	-14.8	100	990	
	3	AZIMUTH	26.7	0.0	17.7	-10.9	100	1000	
	4	AZIMUTH	-39.0	-7.0	43.3	-26.6	100	2450	
-	5	AZIMUTH	-39.0	7.0	43.3	-26.6	100	2450	

Limiting 1 minute mean wind speed in knots
at 10 m above sea level

Wind speed: Automatic
Significant wave height: DNV (ERN)
Mean zero up-crossing period: DNV (ERN)

Rotating tidal current: 1.46 knots
Rotating wind induced current: 0.000*Uwi knots

Figure 14: DP capability envelope for case 5.

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