Specification for

DP Capability Plots

The International Marine Contractors Association

www.imca-int.com

IMCA M 140 Rev. 1
June 2000

The International Marine Contractors Association (IMCA) is the international trade association representing offshore, marine and underwater engineering companies.

IMCA promotes improvements in quality, health, safety, environmental and technical standards through the publication of information notes, codes of practice and by other appropriate means.

Members are self-regulating through the adoption of IMCA guidelines as appropriate. They commit to act as responsible members by following relevant guidelines and being willing to be audited against compliance with them by their clients.

There are two core activities that relate to all members:

- Safety, Environment & Legislation
- Training, Certification & Personnel Competence

The Association is organised through four distinct divisions, each covering a specific area of members' interests: Diving, Marine, Offshore Survey, Remote Systems & ROV.

There are also four regional sections which facilitate work on issues affecting members in their local geographic area – Americas Deepwater, Asia-Pacific, Europe & Africa and Middle East & India.

IMCA M 140 Rev. 1

To ensure a standardisation in the production of capability plots IMCA has prepared this specification for DP vessels. The use of this standard specification will enable a direct comparison of individual vessel's performances and provide an indication of station keeping ability in a common format. The report issued in 1997 updated 107 DPVOA, following input from thruster manufacturers and from industry experience.

This further revision has been produced because revised wind coefficients have been published in API RP2SK and there were errors in Table 3 (peak and crossing periods were the wrong way round and have been corrected) and in Appendix 1, which has been redrafted in part to make it clearer.

This study was prepared for IMCA by Global Maritime, under the direction of its Marine Division Management Committee.

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Appendices

1 Environmental Forces

The components of environmental force are:

i) wind

ii) waves

iii) current

Vessel owners can sometimes provide force coefficients obtained through model testing and whenever possible these should be used in producing the capability plot. If however no model test results are available then forces should be calculated as below.

1.1 Wind

Wind force should be considered on the vessel's hull, below the uppermost continuous deck, and on the superstructure above this deck. For a non-conventional ship shape i.e. a semi-submersible then the total wind affected area at the operating draft has to be considered. For either case, the wind forces should be calculated using accepted standards such as those in Ref. 1, which are also described in Appendix 1. The wind speed should be a one minute mean at a height of ten metres. The literature suggests that a one minute mean wind speed can be approximated between 1.12 and 1.17 times the hourly mean, a value of 1.15 is recommended for the purpose of these calculations (see Refs 3 and 4 for example). In calculating wind affected areas, the following procedures should be followed:

a) The projected area of the vessel's hull, and/or all columns should be included;

b) Shielding effect should be accounted for;

c) The blocked in projected area of several deck houses may be used instead of calculating the area of each individual unit. However when this is done, a shape factor of 1.10 should be used;

d) Isolated structures such as derricks and cranes should be calculated individually;

e) Open truss work commonly used for derrick masts and booms may be approximated by taking 60% of the projected block area of one face;

f) The turning moment caused by wind forces can be considerable, and should be established by referencing areas from the vessel's centre of rotation;

g) The wind velocity increases with height above the water, height coefficients as detailed in Table 1 (Ref. 3) should be used;

h) Shape coefficients for individual areas as shown in Table 2 (Ref. 3) should be used to scale the wind force on different structures;

i) For vessels engaged in trenching, cable laying and other operations that require considerable additional temporary structures an allowance for a typical working spread should be used;

j) For vessels engaged in offshore loading or having more than one operational draft, at least two draft conditions should be calculated.

Height of Area Centroid Above Water Level		
Feet **Over – Not Exceeding**	**Meters** **Over – Not Exceeding**	C_h
0-50	0-15.3	1.00
50-100	15.3-30.5	1.18
100-150	30.5-46.0	1.31
150-200	46.0-61.0	1.40
200-250	61.0-76.0	1.47

Table 1 – Wind force height coefficients (for one minute wind speed)

Exposed Area	C_s
Cylindrical shapes	0.50
Hull (surface above waterline)	1.00
Deck house	1.00
Isolated structural shapes (cranes, channels, beams angles)	1.50
Under deck areas (smooth surfaces)	1.00
Under deck areas (exposed beams and girders)	1.30
Rig derrick	1.25

Table 2 – Wind force shape coefficients

1.2 Waves

Only second order wave forces need be considered for DP capability. The first order forces are not counteracted by a DP system since these are high frequency and need not be considered. In producing capability plots Ref. 1 suggests that wave drift force coefficients can be scaled from data available on other vessels and Ref. 2 provides a set of regular wave drift force coefficients for a small monohull vessel. It is acceptable practice to scale the force from one vessel to another provided they are of a reasonably similar hull or column shape. Alternatively if model test data is not available, then a hydrodynamic computer program can provide the relevant forces.

The relationship between significant wave height, period and mean wind speed will vary depending on the operating location of the vessel. However, for the sake of unity, wind and wave data should be based on a single set of data and it is recommended that averaged values taken from North Sea data are used. Table 3 presents North Sea (Forties) data (which is available from historical records) and the corresponding relationship between significant wave height, wind speed (one minute mean), peak period and crossing period. It is important to note that the North Sea data includes swell, which tends to be around 1 m, with the following relationship.

$$H_s^2 = H_{sea}^2 + H_{swell}^2$$

1.3 Current

The current force exerted on a vessel is assumed to be relatively steady. The force can be calculated as shown in Ref. 1 and in Appendix 1, or based on the results from model tests.

Sig. Wave Height Hs (m)	Crossing Period Tz (s)	Peak Period Tp (s)	Mean Wind Speed Vw (m/s)
0	0	0	0
1.28	4.14	5.3	2.5
1.78	4.89	6.26	5
2.44	5.72	7.32	7.5
3.21	6.57	8.41	10
4.09	7.41	9.49	12.5
5.07	8.25	10.56	15
6.12	9.07	11.61	17.5
7.26	9.87	12.64	20
8.47	10.67	13.65	22.5
9.75	11.44	14.65	25
11.09	12.21	15.62	27.5
12.5	12.96	16.58	30
13.97	13.7	17.53	32.5
15.49	14.42	18.46	35

Table 3 – Relationship between significant wave height, wave period and wind speed

2 Thrusters

One of the largest discrepancies which can occur in the production of capability plots is likely to be in assuming thruster efficiencies, and in the thruster model. The force output from a thruster can only reasonably be determined from full-scale bollard trials but, since these are often not available, assumptions have to be made regarding efficiency and actual force output to move the vessel. To ensure continuity in this aspect we would recommend the following in lieu of full-scale bollard results. However, if the thruster efficiency is known to be poor then the following figures may be reduced accordingly.

2.1 Tunnel Thrusters

Tunnel thruster efficiency should be assumed to be 11 kg/hp (this figure includes an allowance for tunnel losses). Tunnel thrusters can be assumed to give identical thrust in positive and negative directions, unless manufacturer's information says otherwise. For the purpose of these calculations the thrust degradation due to a current flow across the thruster may be ignored.

2.2 Rotatable Thrusters

Rotatable thruster efficiency is assumed to be 13 kg/hp for ahead pitch, and a reduction to 8 kg/hp if the pitch is reversed such that water flow is over the hub. If thruster-hull interaction is likely or known to be significant then an allowance should be made for it. To achieve the most accurate capability plot, the thruster model should take into account the thruster allocation algorithm utilised in the DP system. For example, if it is usual practice to always run the thrusters in a fixed mode then this has to be taken into account. Barred zones for fully rotatable thrusters can limit the ultimate position holding capability and must be included. The DP thruster algorithm may adopt barred zones to prevent thruster/thruster interaction or thruster/position reference degradation, specifically for acoustic and taut wire references.

2.3 Gill Jets

Gill jets can be simulated as rotatable thrusters, but with a thrust to power relationship of 8 kg/hp.

2.4 Rudders

If rudders are incorporated into the DP control system then the effect can be simulated with a tunnel thruster placed at the rudder stock. The rating of the tunnel thruster should be calculated based on the maximum lift available from the rudder. If no performance figures are available, the athwartships thrust should be assumed as 30% of the maximum astern thrust from one propeller (vessel moving astern), assuming the other propeller will provide ahead thrust to counteract forward motion i.e. push/pull mode. The performance of special rudders such as Becker or Schilling designs should be calculated in the same manner, or based on results from full-scale sea trials.

2.5 Main Propellers

These are likely to have high efficiency and suffer little interaction problems with either position references or other thrusters. For main propellers an efficiency of 13 kg/hp should be assumed and the astern thrust limited to 70% when propellers are reversed.

2.6 Power/Thrust Relationship

If full power to the thrusters can not be developed, then it should be assumed that the thrust output is proportional to the square of the propeller's potential speed, N(rpm):

$$T \alpha\ N^2$$

For a controllable pitch propeller, the relationship should be that thrust is proportional to pitch (P%) to the power of 1.7.

$$T \alpha\ P^{1.7}$$

3 Failure Conditions

For some operations the IMCA guidelines require that after the worst case failure, the vessel shall maintain sufficient capability to remain on position within safe limits. For less serious operation, this is not a requirement. The worst case failure condition will be different for individual vessels and is usually identified through a failure mode and effects analysis (FMEA). For most vessels the worst case failure will be the loss of one engine room or one half of the main switchboard, with the consequent loss of half the available thrusters. The thruster distribution available after the worst case failure should leave the vessel both fore-aft and athwartships thrust.

The worst case failure should be identified for each vessel and used as a basis for determining the weather capability suitable for DP operations. It should be kept in mind that the worst case failure mode may not be constant but can vary depending on the vessel's heading. If such a case does arise then the minimum weather envelope should be plotted based on an amalgamation of all the worst case failures. An example showing this is given in Figure 1.

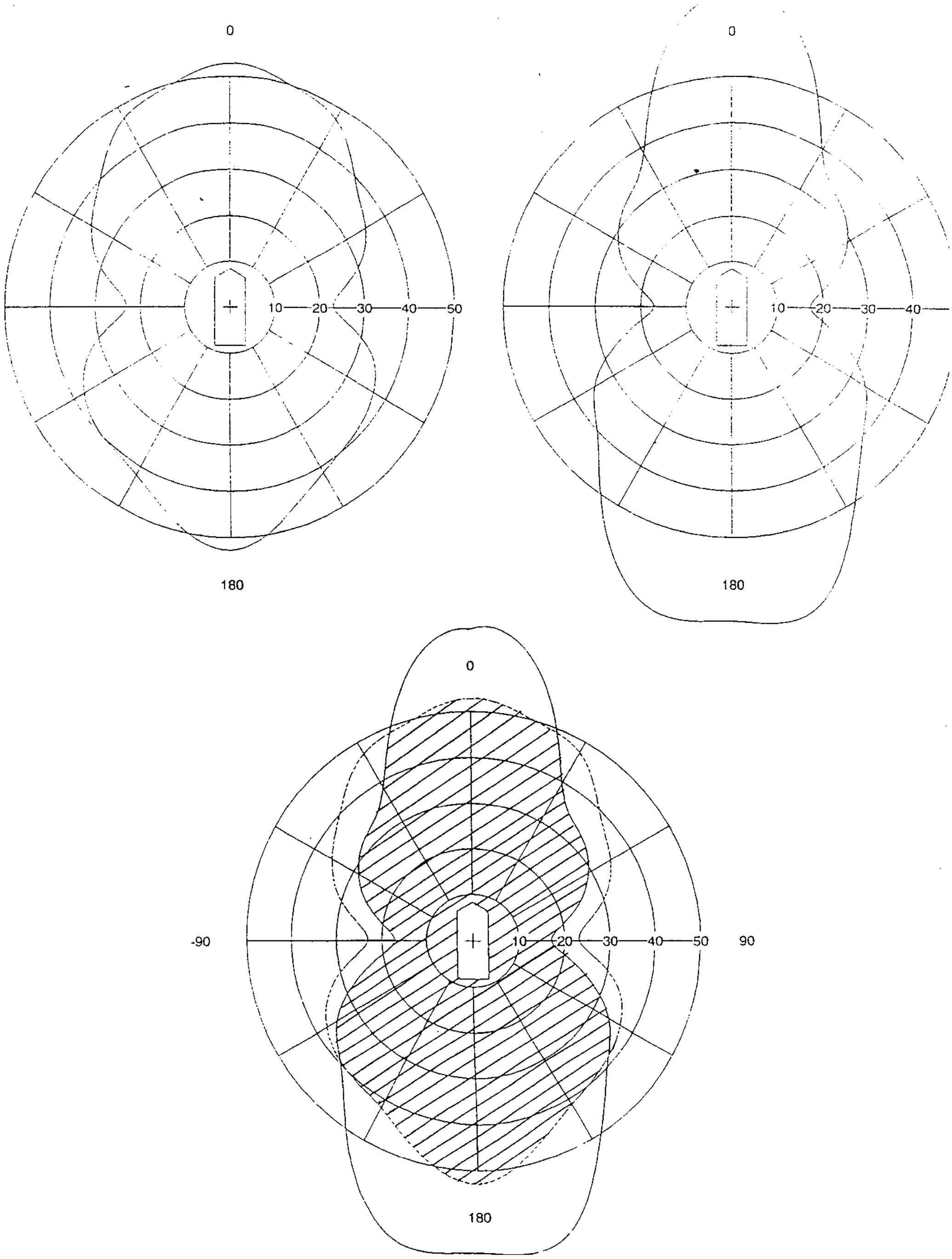


Figure 1 – Evaluation of DP capability at combined worst case failure

4 Presentation

The standardised presentation of results is essential, since it enables a direct comparison between vessels. It also ensures that vessel capabilities are plotted with similar conditions and equivalent failure modes. The following points concerning capability plots should be adhered to:

a) Plots should be produced in polar form, with a wind speed scale between 0 and 50 m/s (15 mm = 10 m/s);

b) Wind, waves and currents should be assumed coincident in direction. The correlation between wind and waves should be as given in Table 3. The current speed should be assumed to be 1 knot and invariant with depth;

c) The limiting wind speed should be plotted at least once every 15° around the vessel. Linear interpolation between points is acceptable;

d) A minimum of two plots is required, under the same weather conditions. Plot 1 should be with all systems fully functional, that is all thrusters able to develop the maximum thrust as required. Plot 2 should be produced on the same scale as Plot 1 and represent the worst case failure mode, or an amalgamation of the worst cases.

5 References

1 Nienhuis U, "Simulation of Low Frequency Motions of Dynamically Positioned Offshore Structures", RINA, 1986

2 English J & Wise D, "Hydrodynamic Aspects of Dynamic Positioning", NECEIS, 1975

3 "Recommended Practice for Design and Analysis of Stationkeeping Systems for Floating Structures", API 2SK (RP2SK), 2nd Edition, 1997

4 UK DEN 4th Edition Guidelines

5 DnV, "Rules for classification of steel ships"

6 MODU (IMO) Code

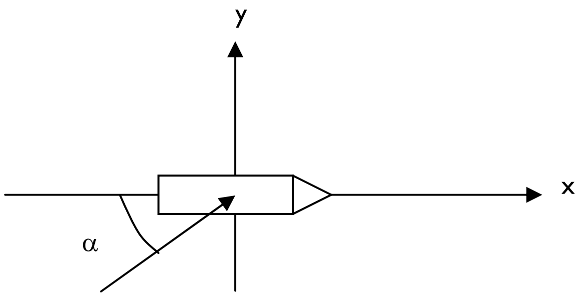
7 Lloyd's "Rules and Regulations for the classification of steel ships"

Methods of Calculating Wind, Wave and Current Forces

(Equations are available in refs 1, 2, 3, 5 and 7)

1 Axis System

X is positive towards bow, Y is positive towards port and Z is positive upwards. The relative environment angle, α, is positive anti-clockwise starting from the stern. Moments are positive anti-clockwise.



2 Wind Forces

Forces on a hull are calculated from the following formulae:

$$F_{wx}(hull) = \tfrac{1}{2}\rho v_w^2 C_{wx}(\alpha_w) A_T(hull)$$
$$F_{wy}(hull) = \tfrac{1}{2}\rho v_w^2 C_{wy}(\alpha_w) A_L(hull)$$
$$F_{wn}(hull) = \tfrac{1}{2}\rho v_w^2 C_{wn}(\alpha_w) A_L(hull) LBP$$

where:

F_{wx} (hull)	= wind force in surge	(kN)
F_{wy} (hull)	= wind force in sway	(kN)
F_{wn} (hull)	= wind moment	(kNm)
α_w	= wind direction	(degrees)
C_{wx}, C_{wy}, C_{wn}	= hull wind coefficients for given wind directions	
ρ	= density of air (1.23×10^{-3})	(t/m^3)
v_w	= wind speed	(m/s)
A_T	= transverse wind area of hull	(m^2)
A_L	= longitudinal wind area of hull	(m^2)
LBP	= length between perpendiculars	(m)

The wind force coefficients are given graphically in Ref. 1. However, they can be conveniently represented by the following expressions:

$$C_{wx}(\alpha_w) = 0.423\cos(\alpha_w)$$
$$C_{wy}(\alpha_w) = 0.8\sin(\alpha_w)$$
$$C_{wn}(\alpha_w) = -0.143\sin(2\alpha_w)$$

Wind forces on the superstructure are calculated using the API method given in Ref. 3 whereby each component of the superstructure is given a projected longitudinal and transverse area, a shape coefficient and a height coefficient. The wind force on each component is then found from:

$$F_{wx}(ss) = C_w\left(C_s C_h A_T(ss)\right)v_w^2$$
$$F_{wy}(ss) = C_w\left(C_s C_h A_L(ss)\right)v_w^2$$

where:

C_w	= API wind coefficient (0.615×10^{-3} to give force in kN)	
C_s	= shape coefficient	
C_h	= height coefficient	
$A_T(ss)$	= superstructure transverse projected area	(m^2)
$A_L(ss)$	= superstructure longitudinal projected area	(m^2)

The wind moment on the superstructure components is calculated by multiplying the total transverse superstructure force by the distance of the centroid of the total transverse superstructure area from midships, and can be expressed as:

$$F_{wn}(ss) = F_{wy}(ss)X_{wc}$$

where:

X_{wc}	= distance between centroid of total transverse superstructure area from midships	(m)

Wind forces on the superstructure for intermediate headings between 0-90° are obtained using the API interpolation procedure given in Ref. 3. This suggests that:

$$F_w(\alpha_w) = F_{wy}(90)\left[\frac{2\sin^2(\alpha_w)}{1+\sin^2(\alpha_w)}\right] + F_{wx}(0)\left[\frac{2\cos^2(\alpha_w)}{1+\cos^2(\alpha_w)}\right]$$

where:

α_w	= wind heading angle	(degrees)
$F_w(\alpha_w)$	= resultant wind force at heading angle α_w	(kN)
$F_{wy}(90)$	= wind force in sway	(kN)
$F_{wx}(0)$	= wind force in surge	(kN)

The longitudinal and transverse components at the heading angle α_w are obtained by resolving the resultant.

$$F_{wx}(\alpha_w) = F_w(\alpha_w)\cos\alpha_w$$
$$F_{wy}(\alpha_w) = F_w(\alpha_w)\sin\alpha_w$$

The wind yaw moment on the superstructure at intermediate heading angles α_w is obtained by multiplying the transverse component by the lever arm of the area.

$$F_{wn}(\alpha_w) = F_{wy}(\alpha_w)X_{wc}$$

In calculating the wind forces on a vessel an allowance should be made for the fact that wind speed is not constant and is subject to gusts. The wind speed should be a one minute mean at a height of 10 m. The literature suggests that a one minute mean wind speed can be approximated between 1.12 and 1.17 times the hourly mean, a value of 1.15 is recommended for the purpose of these calculations (see Refs 3 and 4 for example).

3 Wave Drift Forces

Data available for a similar vessel is scaled according to the method suggested in Ref. 2, which is outlined below.

Frequency is non-dimensionalised thus:

$$\omega' = \omega\sqrt{\frac{V^{\frac{1}{3}}}{g}}$$

where:

ω	= dimensional frequency	(rads/sec)
V	= volume of displacement	(m^3)
g	= acceleration of gravity (9.81)	(m/s^2)

Wave drift force coefficients are non-dimensionalised thus:

$$C_{wvx}(\text{or } \; C_{wvy}) = \frac{F_{wvx}(\text{or } F_{wvy})}{\frac{1}{2}.g.\rho.a^2.V^{\frac{1}{3}}}$$

where:

a	= wave amplitude	(m)
ρ	= density of water (1.025)	(t/m^3)
F_{wvx}	= drift force in regular waves	(kN)
C_{wvx}	= non-dimensional regular wave drift force coefficient	(kN/m^2)

Wave drift yaw moment coefficients are non-dimensionalised thus:

$$C_{wvn} = \frac{F_{wvn}}{\frac{1}{2}.g.\rho.a^2.V^{\frac{2}{3}}}$$

where:

a	= wave amplitude	(m)
ρ	= density of water (1.025)	(t/m3)
F_{wvn}	= drift yaw moment in regular waves	(kNm)
C_{wvn}	= non-dimensional regular wave drift moment coefficient	(kNm/m2)

4 Current Forces

Current forces on a hull are calculated using the method suggested in Ref. 1. Non-dimensional current force coefficients for a variety of vessels are given over a range of headings from 0-180°. These are re-dimensionalised as follows:

$$F_{cx} = \tfrac{1}{2}\rho v_c^2 C_{cx}(\alpha_c).B.T$$

$$F_{cy} = \tfrac{1}{2}\rho v_c^2 C_{cy}(\alpha_c).LBP.T$$

$$F_{cn} = \tfrac{1}{2}\rho v_c^2 C_{cn}(\alpha_c).T.LBP^2$$

where:

F_{cx}	= current force in surge	(kN)
F_{cy}	= current force in sway	(kN)
F_{cn}	= current yaw moment	(kNm)
α_c	= current direction	(degrees)
C_{cx}, C_{cy}, C_{cn}	= hull current coefficients given for current directions	
ρ	= density of sea water (1.025)	(t/m^3)
v_c	= current speed	(m/s)
T	= vessel draft	(m)
B	= vessel beam	(m)
LBP	= length between perpendiculars	(m)

Current forces should be applied as calculated with current speed assumed constant.

It should be noted that in shallow water the current forces will increase as a function of underheel clearance, see OCIMF for tankers.

Specification for Full Scale DP Capability Plots and DP Data Sheets

Global Maritime or other organisations may have provided calculated DP capability plots which, by convention, assume coincident wind, current forces and a fully developed sea. These plots should be used, particularly the worst case single failure plot, to mark actual capability. The following marks can be used:

Date *	Vessel maintained position without heading or position alarm (2°, 2m)
Date 0	Vessel lost position
Date +	Vessel recovered position after initial loss

Note: Date: _________ Wind: _________ Wave: _________ Current: _________

These tests should be made with high gain, in 15° steps from 000°, and in the correct working mode, i.e. cranes raised, and at operational draft. A separate page should be marked for other working conditions. When the weather is 25 knots and increasing you should be able to get a full capability plot or at least 180°. It is important to make sure the position is steady at the time of thruster deselection. To avoid generator load problems the tests should be carried out with the bus tie closed. For each test there should be a note below the plot giving details of the wave and current date. Ideally the wave data should come from a wave rider buoy but if a buoy is not deployed the sea and swell should be estimated and checked later with weather data.

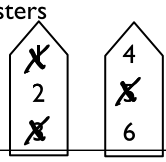
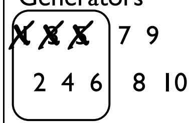
DP Data Sheet

Vessel ____________________ **Company** ____________________ **Date** ____________

Date and type of DP control system(s) installation	Main	Backup		
Last IMCA annual audit	Date	Witness		
Number of:	Engine rooms?	Generators?	Thrusters?	
Are support systems normally separate to each engine room?	Fuel oil	Fresh water system		
	Lub oil	Sea water system		
Can the vessel operate with segregated main electrical systems (bus ties open)?				
State manufacturer and type of power management (PM) system, if fitted.				
Is PM system fully redundant if main switchboards segregated?				
Are the control supplies to the engines and switchboards separate and redundant?	24V	48V	110V	240V
State type of independent position references installed, any limitations, and if pseudo Artemis inputs are possible?	Taut wire	Radio		
	Acoustic	Other		
Does a control or feedback fault cause a thruster to stop?	Auto	Manual		
Does a hydraulic control fault cause a thruster to stop?	Auto	Manual		
What remains on line after the worst case failure which is defined as:	Thrusters	Generators 1 3 5 7 9 2 4 6 8 10		
When was FMEA carried out?	Date	By		

DP Data Sheet

Vessel ______________________ **Company** ______________________ **Date** ______________

Date and type of DP control system(s) installation	Main ADP 503 MK 2		Backup ADP 311	
Last IMCA annual audit	Date 10/2/97		Witness GM	
Number of:	Engine rooms? 2	Generators? 6	Thrusters? 6	
Are support systems normally separate to each engine room?	Fuel oil YES		Fresh water system YES	
	Lub oil YES		Sea water system NO	
Can the vessel operate with segregated main electrical systems (Bus ties open)?	YES			
State manufacturer and type of power management (PM) system, if fitted.	ASEA AUTOMATIC			
Is PM system fully redundant if main switchboards segregated?	NO			
Are the control supplies to the engines and switchboards separate and redundant?	24V YES	48V N/A	110V YES	240V N/A
State type of independent position references installed, any limitations, and if pseudo Artemis inputs are possible?	Taut wire 2 x SIMRAD LWTW		Radio ARTEMIS III	
	Acoustic HPR 309		Other SYLEDIS THROUGH PSEUDO ARTEMIS	
Does a control or feedback fault cause a thruster to stop?	Auto YES		Manual N/A	
Does a hydraulic control fault cause a thruster to stop?	Auto NO		Manual YES	
What remains on line after the worst case failure which is defined as: ONE SIDE OF HV SWITCHBOARD	Thrusters 		Generators 	
When was FMEA carried out?	Date 10/4/95		By GM	