HSE
Health & Safety Executive

OFFSHORE TECHNOLOGY REPORT - OTO 97 055

CLOSE PROXIMITY STUDY

Date of Issue: October 1997

Health and Safety Executive

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INTRODUCTION

Background

The Offshore Safety Division (OSD) of the UK Health and Safety Executive (HSE) is the principal regulatory authority in matters of health and safety on the UK Continental Shelf, (UKCS). The HSE has responsibilities for overseeing the regulation of risks at offshore locations and to ensure that they meet the standards of current legislative requirements. These responsibilities extend to certain marine risks, including those associated with the operation of shuttle tankers at offshore export facilities and in the vicinity of offshore installations. The HSE initiated this study in order to obtain substantive information on the nature and scope of the risks.

Specific Objectives

The principal objective of the close proximity study is to assess the risks of collision during close proximity operations involving shuttle tankers at offshore locations. The secondary objective is to identify suitable standards of control and mitigation so that the risks of collision are reduced to the lowest reasonably practicable levels.

Scope

The scope of the close proximity study is to identify generic hazards associated with offshore shuttle tanker operations by investigation of the technical and operational practices and standards that are currently in place. The following areas were subject to investigation:

- the factors that influence and control the separation between shuttle tanker and installation during offtake operations;
- the types and characteristics of offshore export systems;
- the types and characteristics of offshore shuttle tankers;
- operational procedures;
- emergency procedures and contingency plans;
- safety management elements of operators and tanker owners and managers, including training, competence, reliability/technical studies and risk assessments;
- offshore shuttle tanker selection and design criteria

Method

The close proximity study required the co-operation of a wide range of companies actively involved in offshore shuttle tanker operations so as to obtain first hand information on current technical and operational practices and standards.

A representative sample of companies was selected. All sectors of the industry were represented, including oil companies, tanker operators, training institutions, equipment designers and manufacturers. Meetings were held with each of the selected companies. The issues in the above scope were discussed in some detail. A booklet was prepared for each company in advance of the meeting. It contained the headings and the areas for discussion. At the end of each meeting the information gathered was entered into the company specific booklet. These were used as the basis for producing the report.

Areas for Discussion

There were principally two strands to the discussions. In the first place information was sought on the types and characteristics of offshore export facilities, tanker types, etc. The purpose of gathering information of this type was to give a descriptive overview of the physical characteristics and the nature of offshore shuttle tanker operations. In the second place more detailed information was sought on risk based considerations of shuttle tanker operations.

Project Organisation

The close proximity study is an initiative of the HSE (OSD), who appointed Poseidon Maritime (UK) Ltd (PML) as their consultants to carry out the project work scope. The day to day management and performance of the work scope was the responsibility of PML appointed Project Manager, Mr J Hughes, assisted by Project Engineer, Mr C. Martin. Mr K Pelan, of HSE's OSD was appointed by the HSE to oversee the study and acted as technical liaison with the consultant.

1. OFFSHORE EXPORT FACILITIES - DESCRIPTIONS

Increasingly the shuttle tanker concept is being used as the preferred means of exporting crude oil from offshore production fields to onshore refineries. The direct export of oil by tanker in this way was first developed in more environmentally benign areas than NW European waters, e.g. systems have been in place for many years in African, SE Asian and South American/Caribbean areas. However, the development and the subsequent proving of the concept in the harsh environment of NW European waters has made this mode of export a viable option for a wider range of development areas and applications than was hitherto considered possible. The concept has been implemented, proven and improved over the last two decades in both UK and the Norwegian sectors and it is now a permanent feature of the offshore industry and considered by many in the industry to have the potential for further applications beyond its current range.

There are various types of export facilities, ranging from single point offtake systems linked by pipeline to the offshore production installation to recently developed complex floating production, process and storage systems. Some systems are subsurface and others surface based systems. In evolutionary terms the first type of export facility was the catenary anchor leg mooring (CALM) where the hydrocarbons are transferred by long floating hose to the midships manifold of the offtake tanker. This system needs reasonably good weather and favourable environmental conditions and is not suited to harsh environments or exposed locations, particularly the deep water extremities of the continental shelf.

The first major offshore export facility in the UK was at the Argyll Field in 1975, where a semi-submersible production installation was connected to a single buoy mooring, loading directly into tethered conventional single screw tankers that had only been minimally modified from normal tanker trading.

The concept of offshore exporting via shuttle tanker was then introduced in Norway in 1981 for the export of oil from an ALP on the Statfjord field. This saw the world's first DP shuttle tanker, m/t Wilnora. At that time, the Statfjord experiment was considered to be little more than a temporary measure aimed at bringing forward production start up before the construction of a permanent pipeline. However, initial results were so encouraging that the offshore export facility and the use of DP shuttle tankers became accepted as a permanent life of field solution at Statfjord. Increasingly, since then the concept has been used as a life of field solution for other production areas in the UK and Norwegian sectors. Currently there are more than 20 such facilities. Increasingly the concept is being used for waters in the even harsher environment of the Atlantic Frontier.

This chapter provides an overview of some typical offshore export facilities that are to be seen in North West European waters. General details of each system are provided, as are equipment configurations, modes of operation, typical environmental criteria and system specific risks.

1.1 SURFACE SINGLE POINT SYSTEMS

1.1.1 General Description

There are various types of surface single point loading systems, including an articulated loading platform (ALP) and single buoy mooring (SBM). A common feature of surface single point systems is that their upper sections are above the surface and that they have a single terminal offloading point around which the offtake tanker can normally weathervane. The loading hose and, where relevant, the mooring hawser are connected to the bow section of the offtake tanker.

1.1.2 Articulated Loading Platform (ALP)

An articulated loading platform normally consists of a column that is attached to a gravity base structure on the seabed by a universal joint assembly that allows it to articulate around the x-y axis. A rotating head, weighing in the region of 350 tonnes, sits on the column at a sufficient height above the sea surface to avoid contact with the 100 year wave. Risers are routed partly inside the column and through a swivel joint to the end of a loading boom that is part of the rotating head. From there, normally a 20 inch flexible loading hose in the region of 80 to 90 metres long connects with the loading manifold on the bow of the offtake tanker. Most ALPs are unmanned. The control functions on the ALP are actuated out by telemetry signal from either the offtake tanker or the nearby production installation. ALPs rarely have hydrocarbon storage facilities.

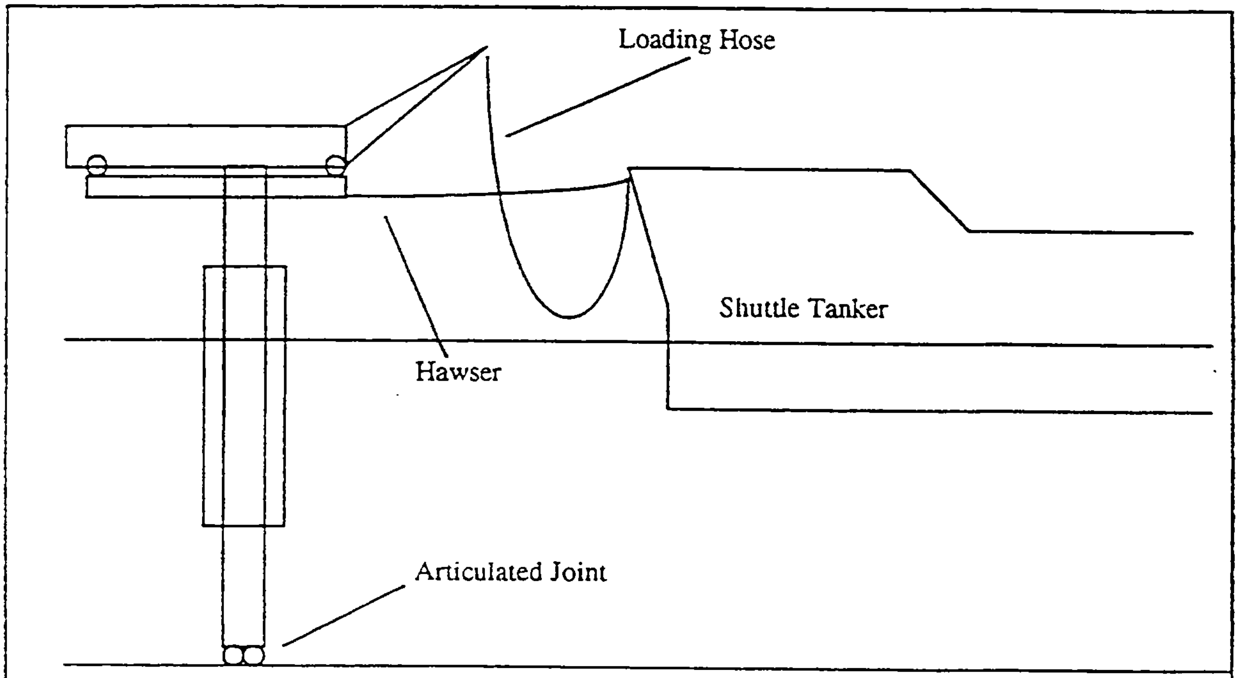


Fig 1.1 - Articulated Loading Column

1.1.3 Single Buoy Mooring (SBM)

Typically a single buoy mooring export system consists of a surface buoy attached by chains to piled anchors on the seabed, as few as six, possibly up to twelve in number The hydrocarbon flowline from the production installation is laid on the seabed and is connected to a seabed manifold, from where a flexible riser carries the hydrocarbons to the surface buoy and from there to the offtake tanker. The surface buoy is invariably fitted with a turntable through which the hawser and flexible export pipeline are routed to the offtake tanker. There are a number of variations of the SBM type system, such as the CALM (catenary anchor leg mooring system) and the SALM (single anchor leg mooring).

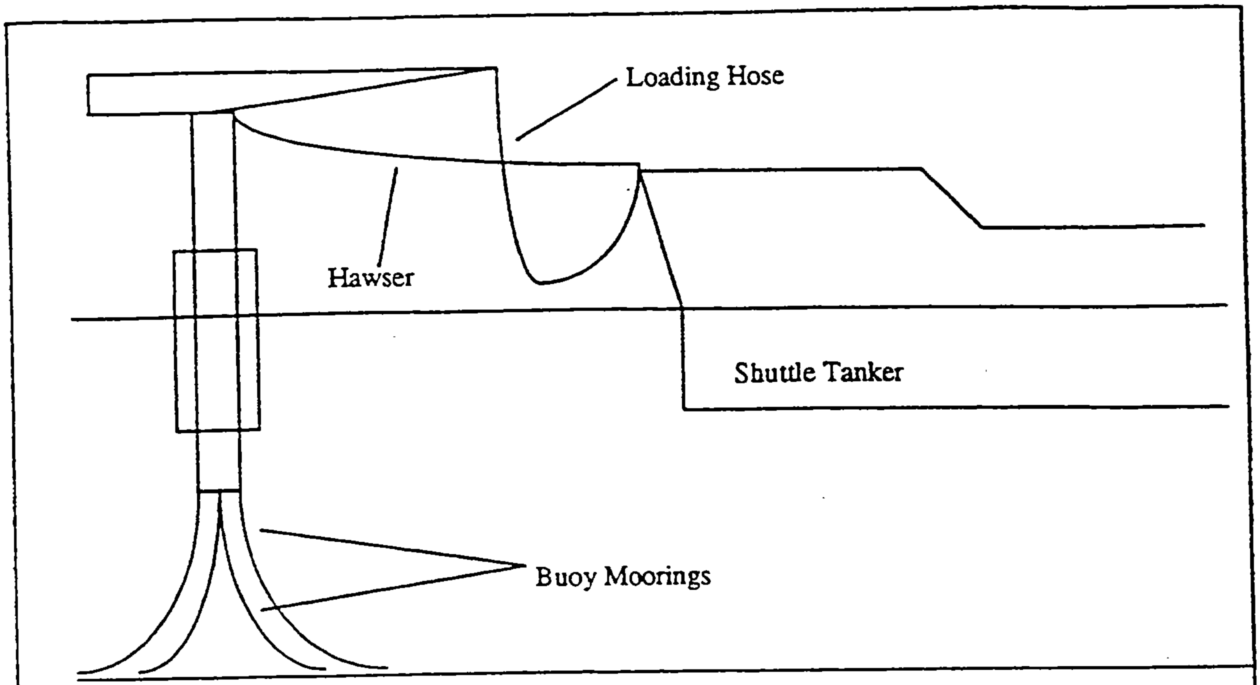


Fig 1.2 - Single Buoy Mooring

1.1.4 Operational Description

It is usual for the offtake tanker to approach the surface single point system from a direction downwind and/or downcurrent. The tanker's line of approach is normally on a near reciprocal heading to the angle of the loading boom and is also generally downstream of the surface mooring messenger and export hose. There may be some restrictions imposed on the tanker's line of approach caused by nearby obstructions such as production installations, mobile drilling rigs or pipelines. These restrictions will normally mean that some angles of approach are unacceptable and that in some cases the approach must be aborted unless the heading of the loading boom can be rotated by an external force, almost invariably by the support vessel. Tanker mooring and positioning systems are typically by hawser and/or by dynamic positioning. Where a hawser is used some preparation work is normally carried out by the support vessel to ensure that the hawser and messenger line are in good order and that they are floating free ready for pick up by the tanker. The pick up of the messenger line by the tanker can be done with the assistance of the support vessel, alternatively, at some facilities the tanker picks up the messenger unaided. Once moored the loading hose is winched onboard the tanker and coupled to the loading manifold.

1.1.5 Specific Risks

Many of the risks associated with the operation of an offtake tanker at surface single point systems are common to other offshore export facilities but on a lesser scale. Specifically, in terms of the collision risk, the consequences are generally less than with some other arrangements, such as ship-shaped FPSOs and FSUs. Surface single point systems are generally unmanned, have little or no hydrocarbon storage, are less vulnerable to impact damage since they are not fixed installations and normally have a circular profile, which would tend to deflect impact energy in the event of a collision.

1.2 SUBMERGED SYSTEMS

1.2.1 General Description

There are various types of submerged systems, including OLS (offshore loading system), STL (submerged turret loading), TCMS (tripod catenary mooring system), SAP (single anchor production) and SAL (single anchor loading). The OLS, originally known as UKOLS was the first type of submerged system and replaced some of the earlier ALPs that had developed cracks. The most significant feature of the submerged systems is that they are designed for hawserless operations. The loading equipment remains subsurface until picked up by the offtake tanker, so that at times when no export is taking place the equipment remains unaffected by surface environmental forces. In each case there is normally a messenger line and small location buoy left on the surface after departure of the offtake tanker, potentially presenting a hazard to surface ships. The STL, TCMS, SAP and SAL systems are designed for operation with conventional tankers that have had only minor modifications to the bow area for accepting the chain mooring and loading hose. There are advantages in using DP tankers at such systems, generally because the manoeuvring and control characteristics of the DP tankers are superior to non-DP tankers, resulting in a widening of the environmental envelope for offtake operations.

1.2.2 Offshore Loading System (OLS)

The offshore loading system consists of a seabed template that is connected to the production installation by a hydrocarbon pipeline. A mid water riser buoy is secured to the template by vertical chain or wire and it is also connected by flexible hydrocarbon carrying hose. There is sufficient depth clearance above the level of the riser buoy to allow deep draught vessels to overrun it. There is generally a swivel arrangement on the buoy turntable that allows unobstructed freedom for the attached offtake tanker to weathervane. The loading hose is connected to the offtake tanker at its bow section in a manner similar to the arrangements for the surface single point loading systems. There is no hawser in the OLS and tanker positioning is by DP.

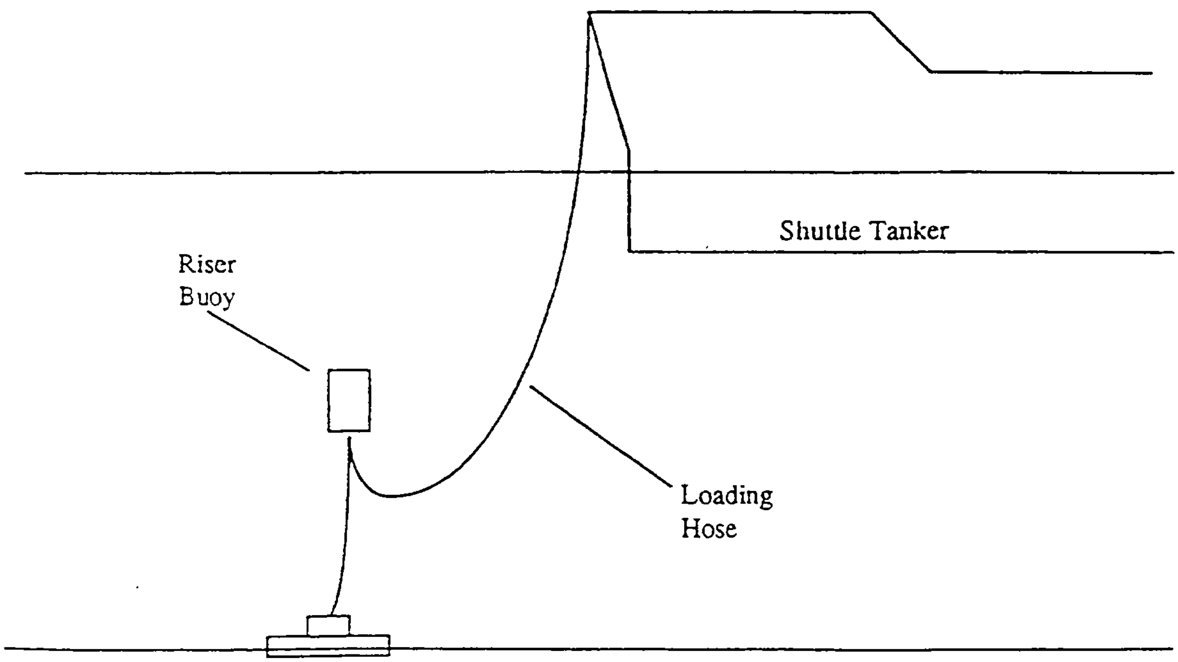


Fig 1.3 - Offshore Loading System (OLS)

1.2.3 Submerged Turret Loading (STL)

The STL system is a refinement of the OLS and is more robust. The STL system is different in a number of ways, particularly that the subsurface buoy is secured to the seabed by a number of anchor chains. In the STL system there is no flexible hydrocarbon riser from the buoy to the tanker, the subsurface buoy being the highest point in the system. The subsurface buoy is designed to fit into a specially configured STL compartment in the hull of the tanker, normally located in way of one of the forward centre cargo tanks. The STL compartment houses the HP swivel around which the tanker can rotate. The subsea mooring system associated with the STL system is not solely for use with offtake tanker operations but can also be used as a means of positioning and transferring hydrocarbons to FPSOs or FSUs. Tankers used with this system need not be DP, the system being capable of operation with conventionally propelled and controlled tankers. However, they must be fitted with STL compartment and HP swivel.

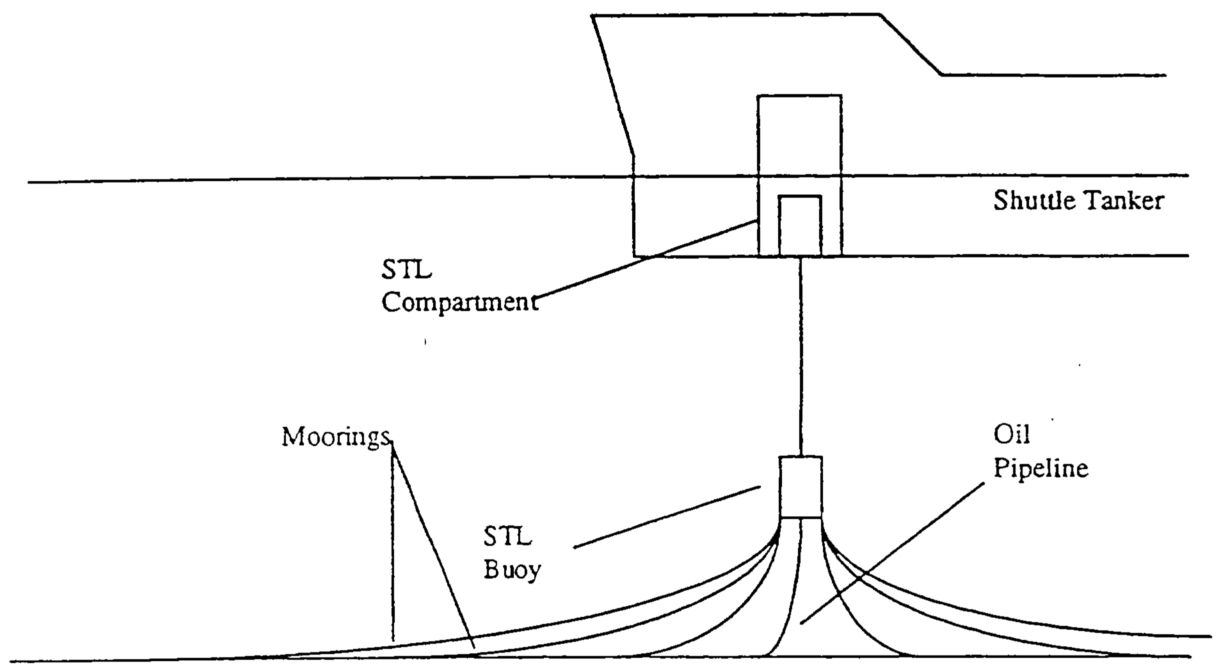


Fig 1.4 - Submerged Turret Loading System (STL)

1.2.4 Tripod Catenary Mooring System (TCMS)

The TCMS is ideally suited to extended well test offtakes where the production/test installation, normally a mobile drilling rig, is located approximately 1 to 2km distant. Although first developed for extended well tests (EWT) of up to 90 days duration, the system is now considered technically capable of carrying out the early production phase in marginal fields and is also considered to have the potential to be a life of field solution.

The mooring system comprises a three legged anchoring system, where the legs of the chain or wire join at a single node point. A chafe chain assembly then rises to the bow of the tanker, where it is connected to a standard OCIMF bow stopper arrangement. The mooring arrangement can be deployed readily by an anchor handling vessel. There is no pre-tensioning in the mooring system. The loading hose is a continuous flexible hose that is normally laid along the seabed from the production installation and is connected to the mid water riser buoy. The tanker only requires to have minimum modification in the form of a loading hose chute that is fitted over its bow. Once connected to the mooring system and the loading hose, the moored tanker can be used as either a shuttle tanker or as a storage facility. In shuttle tanker mode the tanker would load its cargo and then disconnect from the mooring. In storage mode the tanker would remain moored on location and export crude oil via a shuttle tanker operating in tandem. In order to export in this way, it is necessary for the tanker to undergo modifications, in particular having an appropriate discharge system fitted, e.g. stern discharge system (SDS).

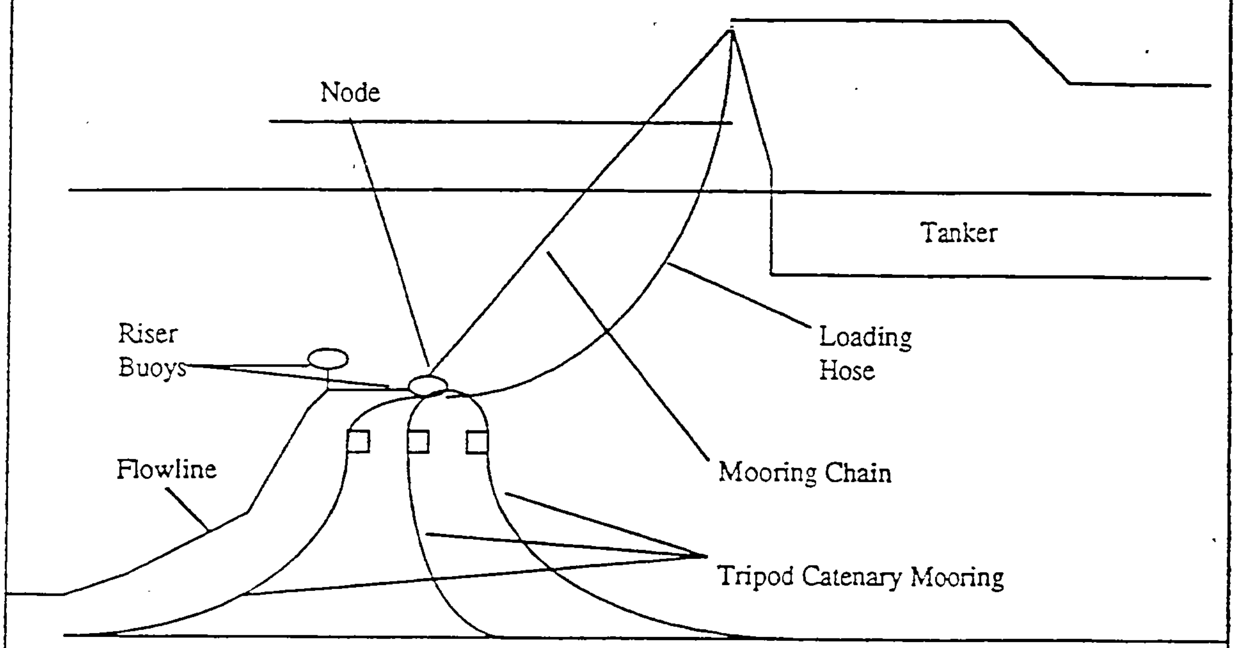


Fig 1.5 - Tripod Catenary Mooring System

1.2.5 Single Anchor Production (SAP) & Single Anchor Loading (SAL)

Both SAP and SAL are similar in concept to the TCMS, being suitable for extended well tests (EWTs), early production phases (EPTs) and also for supporting offshore loading. The mooring principle is based on a suction anchor with a combined high pressure multi-bore swivel and anchor line swivel. The anchor line swivel takes all the forces from the anchor lines which are attached to the tanker through a spring buoy. The high pressure swivel can be installed from the tanker and recovered for repair and maintenance. The SAP/SAL concept provides for safe anchoring and full weathervaning capability even with a number of risers and umbilicals. The riser connection manifold can be located in a suitable area onboard the tanker, even at the midships loading manifold area. The figure below is a representation of the SAP, which is in concept similar to the SAL.

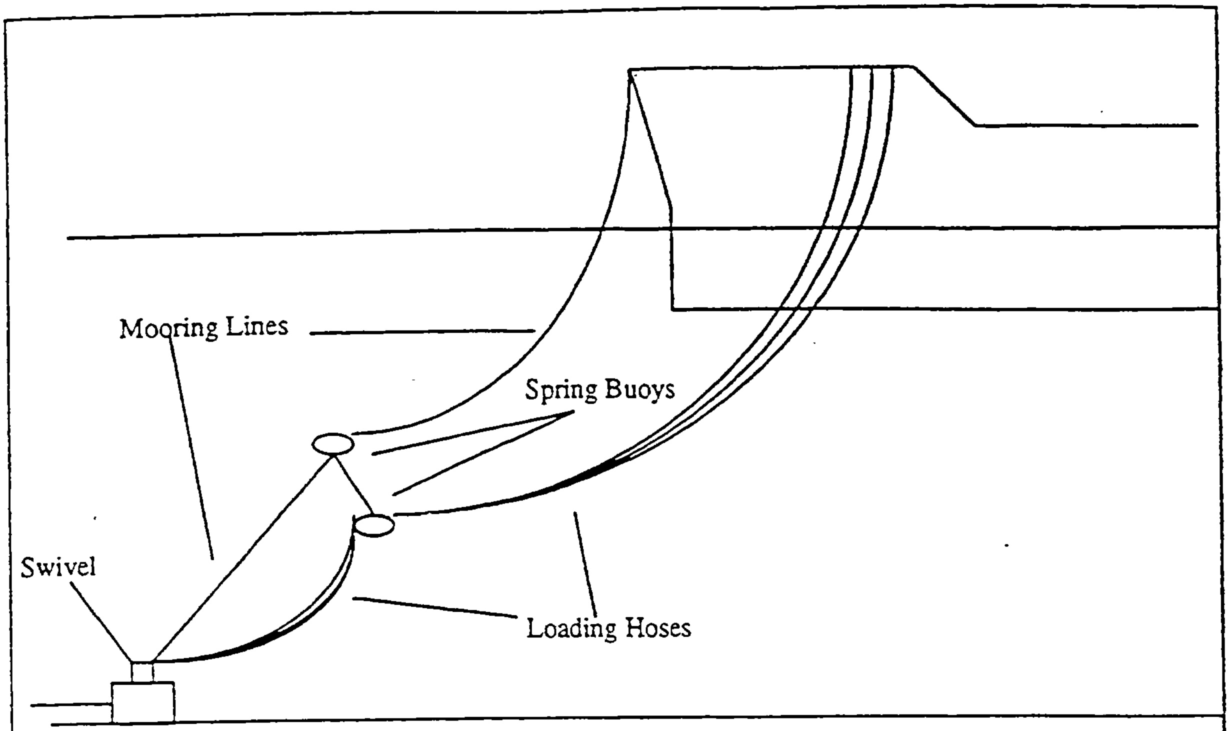


Fig 1.6 - Single Anchor Production (SAP)

1.2.6 Operational Description

The offtake tanker has considerable freedom to manoeuvre on its approach to all of the sub-sea systems referred to above. Unless there are other surface installations in the vicinity there are generally no surface obstructions and thereby no restrictions on the tanker's direction of approach. The presence of obstructions in the vicinity of the location normally results in the establishment of exclusion zones, into which tankers are not allowed. This is particularly relevant to tanker approaches. In all cases, i.e. OLS, STL or TCMS there is generally a surface messenger line that is attached to the loading hose or subsurface buoy and it is therefore necessary for the tanker to know the location of the messenger before starting its approach. Typically a tanker support vessel is used in the approach stages to locate and then pass up the end of the messenger to the tanker.

When moored up in the STL or the TCMS systems, the offtake tanker is effectively tethered to the seabed by the subsea moorings. Where the tanker has appropriate propulsion capability and control systems, such as DP, then the tension in the mooring system can be minimised. There are also options where the tanker can sit without active propulsion thus leaving the STL and TCMS mooring systems to maintain tanker position and to take the mooring tensions caused by hydrodynamic forces acting on the tanker. In all cases, methods are available on board the tanker to monitor position relative to the subsea system. In the STL system monitoring of the tension in the mooring system itself is designed to ensure that the mooring system is not subjected to excessive loads. The position of the offtake tanker can be monitored in a number of other ways, for example, by position reference systems such as DGPS, HPR or Artemis.

Generally offtake tankers can moor up and maintain production at subsurface systems in more adverse environmental conditions than is considered acceptable for surface based offtake systems. For example, experience shows that tankers can approach and moor up at an OLS where significant wave height (Hs) is 4.5m, disconnecting when Hs reaches 5.5m. However, the environmental envelope for STL systems is considerably greater, with typical values for tanker approach and mooring being in the region of Hs equal to 5 to 5.5m, with the tanker able to remain on location in extreme environmental conditions, not requiring disconnection until Hs reaches 10m or, in some cases, 15.5m. The environmental conditions required for mooring at TCMS is Hs equal to 4m and the system is capable of continued operation in sea states up to 8m.

1.2.7 Specific Risks

One of the principal advantages of the STL system is that the environmental envelope is considerably more extensive than with other sub-sea systems. STL systems are able to support continued operations in extreme environmental conditions that other systems find untenable. The ability to maintain production in extreme conditions does not significantly increase the risk of damage or loss, since there are generally no surface obstructions presenting a risk of collision. Where there exist environmentally induced hazards, such as extreme wave height or extreme subsea currents causing unacceptable excursions or tensions in the mooring system, then the risk of damage can be averted by emergency disconnection. This is an option in all systems.

1.3 SURFACE PRODUCTION AND STORAGE SYSTEMS (FPSO or FSU)

1.3.1 General Description

The two principal systems are floating storage units (FSU) systems and floating production storage and offloading (FPSO) systems. Typically both involve the use of ship shaped vessels secured to the seabed by a number of different mooring systems, such as STL. In both cases the FSU and FPSO are able to weathervane, at some locations without restriction, but at others with only a limited degree of freedom. The normal means of export is by stern loading to an offtake tanker. The generic term for this is tandem loading. The offtake tanker can be either DP controlled or a conventional tanker. As will be seen in section 1.4 and in Chapter 2 there has been a trend for tankers to become more sophisticated with greater manoeuvrability and redundancy, however there are still some shuttle tankers that have conventional propulsion and control configurations.

1.3.2 Floating Storage Units (FSU)

FSUs are either converted tankers or custom-built vessels. There are a number of different ways of securing the unit to the seabed, such as by an STL system where the securing point is normally in a specially constructed compartment in the hull of the unit or by a yoke type surface connection located directly on the bow of the unit. Hydrocarbons are pumped by subsea pipeline to the FSU from the production installation some distance away, normally in the region of 1.5 to 2km. The FSU loads directly into its cargo tanks and when nearing completion an offtake tanker arrives to carry out a tandem offload using the stern discharge system, (SDS). There are no process facilities on board the FSU, only storage. Storage capacities vary and can be as much as 600,000 barrels of oil.

1.3.3 Floating Production Storage and Offloading (FPSO)

Many of the features associated with the FSU are shared by the FPSO, the principal differences being that there are process facilities on board the FPSO unit, consisting of crude oil separators, gas compression plant, flaring, venting systems and chemical injection modules. Normally FPSOs are ship shaped and may be a custom built installation or a converted tanker. Methods of securing the FPSO to the seabed are invariably by a submerged mooring system, by STL or by a variation of the concept. In addition, export of the hydrocarbons is normally by SDS to an offtake tanker in a tandem arrangement.

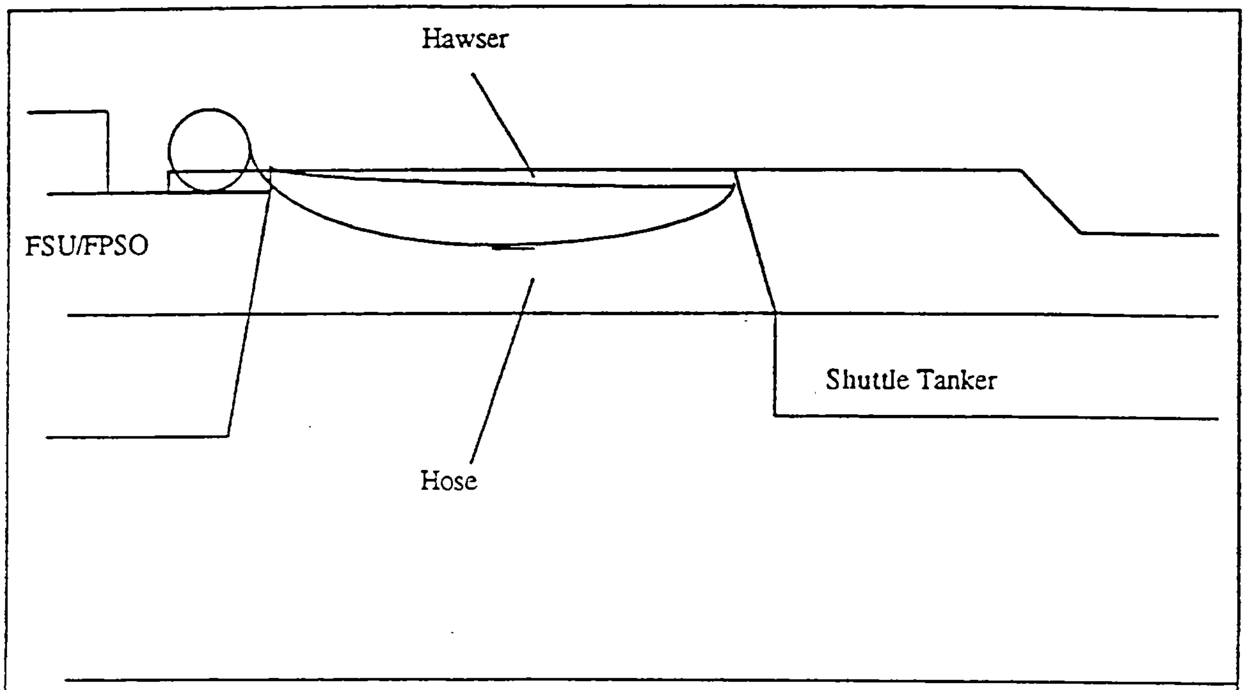


Fig 1.7 - FSU/FPSO

1.3.4 Operational Description

It is normal for the tanker to approach the stern of the FSU or FPSO on a parallel heading. An FSU or FPSO will normally lie head to the prevailing environment. Some installations are free to weathervane, whereas others have propulsion capability, enabling the adoption of a preferred heading for the approach and throughout the export. It is normal for the direction and speed of the tanker approach to be subjected to procedural controls from 10 nautical miles out. Frequently there are restricted sectors that the tankers are not allowed to enter. Mooring and hook up can be either with the assistance of a support vessel, but increasingly, the entire operation is carried out without external assistance, in which case rocket line, messenger line, hawser and hose are transferred directly to the offtake tanker from the stern of the FSU or FPSO. The transfer of the rocket line normally starts with the tanker at a 100 metres stand off position, maintaining its position on DP.

When moored and hooked up to the FSU or FPSO the tanker maintains position by DP with the hawser acting only as back up. There are considerable hydrodynamic interactions between the export facility and the offtake tanker, normally to a much greater degree than is experienced at other export facilities, such as surface buoys or loading columns. Part of the reason for this is the difference in underwater shape and mass between a fully loaded deep draught FSU or FPSO and a lighter shallow draught offtake tanker. As the loading progresses the balance of forces acting on the underwater shapes can equalise and then become biased so that greater forces act on the tanker than on the export facility.

1.3.5 Specific Risks

The greatest single marine risk is that of collision between the FSU or FPSO and the offtake tanker. The hazards are potentially much more severe than other export facilities since, in physical terms, the inherent forces, physical masses and exposure of personnel are greater. Where, as in most cases, the positioning of the offtake tanker is controlled by DP then the reliability and effectiveness of the DP system and its peripherals are of utmost importance. In terms of dynamic interaction the presence of the DP shuttle tanker poses as much of a threat to the FSU or FPSO as does the FSU or FPSO to the DP shuttle tanker. However, apart from a select few examples, the operational risk reduction measures are mainly taken by the DP shuttle tanker.

The better the operational performance and redundancy levels of the DP system then the more remote the chance of collision. Much of this report will concentrate on the adequacy of DP shuttle tankers to carry out the offtake function in close proximity to FSUs and FPSOs.

In brief the report will cover the following DP associated areas in relation to the design and operation of DP shuttle tankers.

- Principles of DP operations, inc. philosophy of DP shuttle tanker operations
- Overview of DP systems and equipment, inc. typical failure modes and control measures
- Principles of DP redundancy, international codes and guidelines
- External and internal DP verification schemes
- Operational problem areas associated with DP shuttle tankers
- DP operational procedures
- DP human factors

1.4 TABULATED ASSESSMENT

The following table draws together some of the principal topics contained in this chapter. It is acknowledged that the export systems referred to in column 1 do not make up a complete list of system types. There are other systems that have not been considered. However, all other systems are conceptually related to the systems below, none being radically different. The table below has been developed to show the main operating scopes, sensitivity indices and tanker types that are considered to be the most suitable for each system. This involves qualitative assessment. The decision making principle used in the qualitative assessment is based on the nature and results of discussions held with individuals and companies that are directly involved in offshore offtake operations and have participated in the project. The assessment is consistent with their majority viewpoint, being based principally on operational experience and knowledge but also influenced by the exercise of competent operational and safety management judgement.

1.4.1 Qualitative Assessment Table

Type	Title	DP Tanker Application	Non DP Tanker Application	Close Proximity Sensitivity Index	Environmental Sensitivity Index	EWT	EPT	Life of Field
ALP	Articulated Loading Platform	1	2/3	2	1	3	3	1
SBM	Single Buoy Mooring	1	2/3	2	1	3	3	1
OLS	Offshore Loading System	1	3	3	2	3	3	1
STL	Submerged Turret Loading	2/3	1	3	3	3	3	1
TCMS	Tripod Catenary Mooring System	2/3	1	3	3	1	1	2
SAL	Single Anchor Loading	2/3	1	3	3	1	1	2
SAP	Single Anchor Production	2/3	1	3	3	1	1	2
FSU	Floating Storage and Offtake	1	2/3	1	1	3	3	1
FPSO	Floating Production and Storage Offtake	1	2/3	1	1	3	3	1

Table 1.1

1.4.2 Discussion

DP Tanker Application
Key: 1 = most practicable, 2 = practicable, 3 = least practicable

DP tankers can be used at all offshore export facilities referred to in this Chapter. Experience shows that DP tankers are most frequently used at and are best suited to FSU, FPSO, ALP and SBM, where there is surface structure in close proximity. Increasingly, where new surface based export facilities are being developed DP tankers are selected as the preferred choice on grounds of safety and performance. Most surface based export facilities are still equipped with a hawser and although the tanker may be under DP control for the duration of the offtake, it also remains connected by hawser. As can be seen in Chapter 5 where discussion centres around hazards, the hawser connection, although partly providing certain safeguards against dangerous loss of position, also presents its own hazard to the safety of the offtake operation. There is considerable weight of opinion in the conventional offtake tanker operating sector that is in favour of hawserless DP offtake operations. This would avoid some of the hawser related problems and would lead to a reduction in risk.

The only subsea system that requires the use of DP tankers is the OLS, where the system does not have an attached mooring. All other subsea systems have integral moorings.

Non-DP Tanker Application
Key: 1 = most practicable, 2 = practicable, 3 = least practicable

STL, TCMS, SAL and SAP systems have been designed specifically for use by non-DP tankers, each system being equipped with an integral mooring system. The solutions presented by these systems are all based on the same operational principle, viz., that the export facility is located some distance away from the production or test facility and that the oil is pumped along a pipeline. The most frequently encountered option is to lay a flowline along the seabed from the production installation to the subsea export facility. A central tenet in the development philosophy of such systems is to provide clear water between permanent production installations or moored rigs and the offtake tanker, thus reducing the close proximity risks. Additionally, in the cases of TCMS, SAL and SAP the systems have been developed for ease of deployment by surface craft, e.g. the TCMS system can be deployed by an anchor handling vessel.

As can be seen from the table it is only the OLS system for which non-DP tankers provide the least practicable solution. In fact, as described in the narrative of this chapter, the OLS system can not reasonably operate without a DP tanker, there being no integral mooring.

Non-DP tankers can be used at surface based systems, viz., ALP, SBM, FSU and FPSO. There are a number of examples where current offtake operations at such facilities are carried out using non-DP tankers, the tankers being tethered by tensioned hawser to the facility. As can be seen in Chapter 5 such arrangements introduce additional hazards. It is the current trend in the industry that an increasing number of operators are turning their backs on tensioned hawser systems and adopting offtake solutions involving DP tankers.

Close Proximity Sensitivity Index
Key: 1 = most sensitive, 2 = sensitive, 3 = least sensitive

A number of elements have been considered in determining the close proximity sensitivity index of each of the export systems. Decisions have been made qualitatively but remain consistent with the viewpoints expressed by the participants throughout the course of the project. One of the principal considerations has been dynamic interaction between the offtake tanker and the export facility. It is widely recognised that the most significant dynamic interactions are to be experienced between the offtake tanker and another ship shaped installation, such as a FSU or FPSO, especially when in tandem loading mode. The practical problems associated with this mode are discussed in Chapter 5. Another consideration has been the physical size of the units and also exposure of personnel to potential harm in the event of failure. A rating of 1 is the most sensitive index and indicates that, other things being equal, there is greater risk of collision risk than with other index ratings. For example, a DP tanker that is carrying out an offtake some 60 metre astern of an FSU has a more sensitive close proximity rating than if it were on location at an STL, since not only are the potential consequences much more severe but also the probability of collision is also much higher. The same reasoning applies to a non-DP tanker at these locations, where the rating of 1 still applies to the FSU and lesser rating to the STL.

As can be seen from the table it is only the FSU and FPSO that attract a rating of 1. The other surface based systems, ALP and SBM, have a rating of 2 and the subsea systems have the lowest ratings. It is recognised that a number of subsea systems will attract a higher rating than 3. This will depend on the proximity of adjacent obstructions, such as production platforms and mobile drilling rigs.

Environmental Sensitivity Index
Key: 1 = most sensitive, 2 = sensitive, 3 = least sensitive

Many of the principles used to determine the environmental sensitivity rating are similar in nature to those used in determining close proximity indices. Clearly there are some systems, which are extremely sensitive to environmental conditions, in particular the effects of the wind, sea height, swell, period and current. To a large extent the surface based systems are more vulnerable to the changes in environmental conditions than are the subsea systems. Environment induced problems associated with the surface systems are discussed in Chapter 5.

Single point surface systems such as ALP and SBM are less vulnerable than are FSUs and FPSOs, since, other things being equal, the single point systems are largely unaffected by environment induced movement, such as rotation, rolling and pitching. The tankers that are connected to single point systems are generally free to rotate around a small pivotal area, whereas in the FSU and FPSO systems it is generally the case that the attached tanker and the export facility both adopt environment induced headings, although this is mitigated somewhat where there is fixed heading control.

Extended Well Test (EWT)
Key: 1 = most suitable, 3 = least suitable

An extended well test is generally considered to be a process for determining the production behaviour of the well. Although it is difficult to put a timescale on the duration of EWTs, typically they do not exceed 90 days in length.

Only two categories of index have been chosen for EWTs. In deciding into which category to place each system it has been necessary to consider operational and commercial realities. Practical considerations dictate that the offtake system used to support the EWT must be cost effective and reasonably straightforward to deploy and recover. As indicated previously in this Chapter a number of systems have been specifically designed and developed to meet these requirements, viz., TCMS, SAP and SAL. None of the other systems meets these operational and commercial realities.

Early Production Test (EPT)
Key: 1 = most suitable, 3 = least suitable

An early production test differs from an EWT in a number of small ways, although the boundaries are not entirely clear. In general, whereas an EWT is carried out as an information gathering exercise to find out more about the characteristics of the well, an EPT is carried out principally for commercial considerations. In addition an EPT generally requires the regulator to approve of a well development plan. This is not required for an EWT.

As a result of the lack of clear definition between an EWT and an EPT the categories that have been chosen for each type of system are the same as for EWT.

Life of Field
Key: *1 = most suitable, 2 = suitable, 3 = least suitable*

Categorisation has been consistent with the operational experience and expectations. All systems apart from TCMS, SAL and SAP are best suited to life of field solutions. However, the prospect of using the three above mentioned systems in supporting life of field solutions should not be totally discounted, since experience shows that they have supported EWTs and EPTs over prolonged periods in the harsh environment of the UK and Norwegian continental shelves even in winter conditions. Clearly each case should be treated on its own merits, but the overriding practice at the moment is to develop life of field solutions that have been given an index rating of 1 and not those that have a rating of 2.

2. SHUTTLE TANKER - TYPES and DESCRIPTIONS

2.1 LOADING SYSTEMS

2.1.1 General Description

The first shuttle tankers were standard ocean going trading tankers that tied up to buoys using conventional mooring systems, winch equipment and fairleads designed for securing the vessel to a jetty in a harbour. Generally the loading hose was long enough to stretch from the loading buoy to the tankers midships manifold. There are a number of obvious disadvantages with this type of system, e.g., limited environmental envelope, protracted mooring and disconnection times and increased likelihood of personal injury because it was labour intensive.

The tankers were next fitted with a bow loading system. This allowed the tanker to attach itself to the loading station by a single line via a quick disconnect arrangement. A permanent loading line was run from the tanker's midships manifold to the bow and a system of remote closing valves and a quick disconnect coupling fitted for attaching the hose to the loading line. The bow loading system was a considerable advance in ease of connection and disconnection and also enabled an emergency release to be initiated from the tanker. For tankers operating in the North Sea a standardised coupling design was developed enabling a shuttle tanker to visit all offshore export facilities. As described in the previous chapter there are now a number of different types of offshore loading facilities, all of which have compatible hawser and hose connection systems.

2.2 TANKER PROPULSION SYSTEMS

2.2.1 General Description

In the earliest systems, while attached to a loading buoy, a small but steady thrust away from the station was required to prevent the shuttle tanker from over-running the buoy. Steam turbine engines are easier to control at low speeds, but became rare, principally because they were not as economical as Diesel engines. Therefore controllable pitch propellers coupled to Diesel engines became the established configuration thus allowing the engines to run at more suitable speeds while maintaining a low thrust.

Shuttle tankers are generally in the 80,000 to 130,000 deadweight tons and proved difficult to control at the very low speeds required when approaching the loading station. A transverse bow thruster was the first addition for assisting the vessel's manoeuvring capability, this modification proved so successful that subsequent designs used two bow thrusters and then one or two stern thrusters. Occasional tankers with twin screws showed improved manoeuvrability with the benefit of improving redundancy in event of failure. The most advanced technical designs now incorporate two bow and two stern thrusters and twin main propellers. Some shuttle tankers have adopted a Diesel electric system with electric motors for the main propeller as well as the thrusters.

Future developments may include twin azimuth propellers at the stern, replacing both the main propellers and the stern thrusters. Azimuth thrusters at the bow are under consideration because they have the advantage of being deeper in the water, therefore, increasing the vessel's ability to maintain position in heavy swells.

2.3 CONTROL SYSTEMS

2.3.1 General Description

Early shuttle tankers had a simple bridge control system for the main engine speed and propeller pitch. Control of the bow thruster was by a single lever controlling the pitch. Control of the main propeller and transverse thrusters were later integrated into a single joystick with heading control.

Dynamic Positioning (DP) systems were then developed for shuttle tanker use. A DP system takes information from vessel status sensors (Gyro compasses, vertical reference sensors and wind speed sensors) and position reference sensors (Hydroacoustic Transponders, Artemis, and satellite position reference systems such as DGPS), analyses this information and adjusts the propeller thrust to maintain position within defined limits. Early systems used a single computer, later systems have utilised a twin computer arrangement capable of instant change over from a failed on line computer to the stand-by computer without degradation of station keeping.

2.4 TYPICAL TANKER CONFIGURATIONS

The table below describes typical configurations for four types of shuttle tanker. The types described here are indicative only and, although modelled on tankers that are either currently in service or under construction, they do not refer to specific tankers.

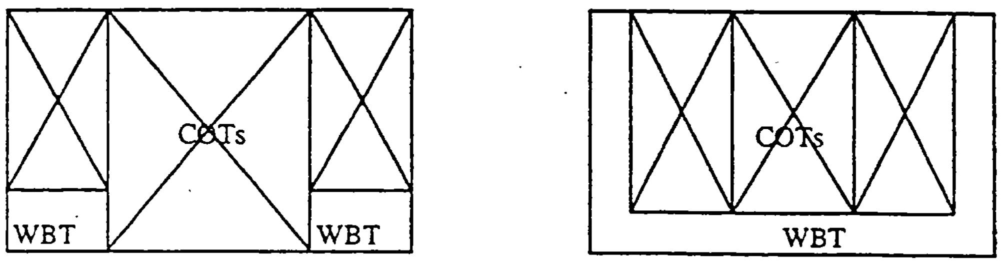
TANKER FEATURES	TANKER A Early	TANKER B 1st Generation	TANKER C 2nd Generation	TANKER D 3rd Generation
Hull and General Arrangement	Single skin hull. Segregated ballast. Accomm. and mach. spaces aft. Cargo pump room located between cargo tanks and engine room.	Double skin hull (incomplete) Segregated ballast. Accomm. and mach. spaces aft. Cargo pump room located between cargo tanks and engine room.	Double skin hull. Segregated ballast. Accomm. and mach. spaces aft. No cargo pump room.	Double skin hull. Segregated ballast. Accomm. and mach. Spaces aft. Cargo pump room located between cargo tanks and engine room.
Cargo Loading System	Bow loading system	Bow loading system	Bow loading system. STL system.	Bow loading system
Cargo Tank Configuration	Tank nos 1 to 5 port, centre and stbd	Tank nos 1 to 5. Port, centre and stbd	Tank nos 1 to 7 centre	Tank nos 1 to 5 port, centre and stbd
Ballast Tank Configuration	Tank no 3 port and stbd	Tank nos 1 to 5 port, centre and stbd	Tank nos 1 to 5 wings, port and stbd	Tank nos 1 to 5 wings, port and stbd
Main Engine Type	Single slow speed, two stroke Diesel coupled directly to propeller shaft.	Single slow speed, two stroke Diesel directly coupled to propeller shaft.	Two medium speed, four stroke Diesel engines each coupled via a clutch to a gear box and propeller shaft.	Two slow speed, two stroke Diesels directly coupled to propeller shaft.
Main Propulsion Type	Single main CPP	Single main CPP	Two main CPPs	Two main CPPs
Bow Propulsion Type	None	Two bow thrusters 2 x 1500hp	Two bow thrusters 2 x 2000hp	Three bow thrusters 3 x 2300hp
Stern Propulsion Type	None	Single stern thruster 1 x 1500hp	Single stern thruster 1 x 1500hp	Two azimuth stern thrusters 2 x 2300hp

TANKER FEATURES	TANKER A Early	TANKER B 1st Generation	TANKER C 2nd Generation	TANKER D 3rd Generation
Rudder	Single conventional rudder	Single high lift rudder	Two high lift rudders	Two high lift rudders
Power Generation	3 x identical DGs supplying 440V AC at 60Hz to main swbd.	5 x identical DGs in single ER supplying 440V AC at 60Hz to main swbd.	4 x identical DGs supplying 660V AC at 60Hz to main swbd, plus shaft alternators driven off each main engine	4 x identical DGs, 2 in each ER, supplying 6.6kV AC at 60Hz to main swbd.
Power Distribution	Single main swbd in one section with no bus-ties.	Single main swbd split by auto trip bus-tie. 2 x DGs on port side and 3 x DGs on stbd side of the bus. Main service pumps split between two busses. Bow thrusters supplied from different busses.	Single main swbd in two sections, one in each ER, connected by auto trip bus-tie. 2 x DGs on port side, 2 on stbd side. Main service pumps split between busses. One bow thruster and one stern thruster supplied from each swbd.	Single main swbd in two sections, one in each ER, connected by an auto trip bus tie. 2 x DGs on port side, 2 on stbd side. Main service pumps split between two busses. One bow thruster and one stern thruster supplied from each swbd.
DP Control Location	None	Bow Control House	Bow Control House	Navigating Bridge
DP Control System	None	Simplex Simrad ADP100 2 x VRUs 2 x wind sensors 2 x gyro compasses 2 x draught gauges	Duplex Simrad ADP 702. 2 x VRUs 2 x wind sensors 2 x gyro compasses 2 x draught gauges	Duplex Cegelec 902 2 x VRUs 2 x wind sensors 2 x gyro compasses 2 x draught gauges
DP Position References	None	Artemis Mk IV HPR system DGPS/DARPS	Artemis Mk IV Fan Beam Laser HPR System DGPS/DARPS	Artemis Mk IV Fan Beam Laser HPR System DGPS/DARPS
Cargo Pump Configuration	3 x cargo pumps each powered by steam at 30 bar supplied from 2 boilers.	2 x boilers supplying steam at 16 bar for 3 cargo pumps, stripping pumps and heating units.	7 X motor driven deep well cargo pumps	2 x 6.6kV cargo pumps each supplied from a different side of main bus.
Ballast Pump Configuration	1 x electric ballast pump supplied from the main swbd.	2 x electric ballast pumps each supplied from different sides of the main bus.	2 x motor driven deep well ballast pumps.	2 x 6.6kV motor driven ballast pumps each supplied from different side of the main bus.
Cargo and Ballast Valves	Hydraulic control from CCR in the accommodation block.	Hydraulic control from CCR on bridge	Hydraulic control from CCR in the accommodation block	Hydraulic control from CCR on bridge

Table 2.1

2.4.1 Hull and General Arrangements

Tanker hull form types have undergone considerable development in the past 20 years or so and this has had an impact on shuttle tankers. Traditionally tanker hulls were single skinned so that the piercing of the outer side shell or bottom plating would inevitably lead to an escape of hydrocarbons and environmental damage. One of the first double skin types saw the development of a modified arrangement in which the side tanks were divided into upper and lower sections with the lower section for ballast, but the upper section for crude oil. This arrangement is designed to afford protection to the tanker in the event of grounding, when the bottom plating, in the region of the turn of the bilge, is most vulnerable. However, the most recent development is for the double skin to be wrapped right around the cargo carrying tanks. This reduces the risk of escape of hydrocarbons in the event of piercing of the outer side shell.



Tanker B (Double Skin Incomplete)   Tanker C and D (Full Double Skin)

Fig. 2-1 Schematic Arrangement of Double Skin Tanker Hull Forms

The traditional arrangement is to have a cargo pump room in a space between the cargo tanks and the engine room. A cargo pump room is hazardous. Over the years many accidents have occurred in these compartments. Therefore the measures taken to control the hazards and reduce the risks in this area have resulted in the implementation of strict procedures, extensive HC monitoring, gas detection, alarm and protection systems. Effective management of the pump room can reduce the risks significantly, so much so, that some tanker operators have still to experience their first pump room accident.

One other way of reducing the risks has been to design an alternative cargo pump without a pump room. This has seen the emergence of deepwell pumps. This radical change of design philosophy led to the development of deep well pumps in the cargo tanks. Although this feature avoids some of the obvious problems related to the cargo pump room, there are a number of operational disadvantages as well as additional cost implications. As a result the practice of installing deep well pumps in shuttle tankers is not widespread.

2.4.2 Cargo Loading Systems

Although all tanker types described in the tables are equipped with bow loading systems (BLS) there are still tankers that carry out offshore offtakes using the conventional midships loading manifold system. Couplings and hose types have become standardised over the years and now in general there is compatibility across the entire range of export facilities and tanker types for hoses as well as for mooring facilities. The hose used for BLS is standard 16 inch ID. It is made up in sections and flanged together. Typical BLS units comprise the following items; bow coupler, coupler power pack, coupler controls, emergency shutdowns. The hose used for systems such as TCMS is typically one piece flangeless. The coupler on standard BLS units is hydraulically operated and is normally pressurised from a dedicated power pack.

In the early systems, e.g. tanker B, the coupler manifold is located on the open forecastle deck. In more modern systems, such as tankers C and D, the coupler is located in a recess in the bow. In addition, for all types there is normally a hose/chain handling system on the forecastle. In the early types of shuttle tanker the bow control house and the coupler arrangements were located on the same deck level. Bow configurations have changed over the years and to the benefit of safety and operational performance. For example, tanker C has an improved set up where the bow control house is one deck level above the coupler equipment. Tanker D has no bow control house.

During the connection phase the hose end coupling is aligned to the coupling on the loading manifold. When the two ends are aligned properly the coupler claws are hydraulically locked. This operates a proximity switch. Once properly connected the coupler end valve is opened. The coupler is dry break, so that, in the event of a failure, ESD 2 or overpull on the hose system, the valve closes and the claws are released. There are typically two levels of emergency shutdown (ESD), activated manually from the shuttle tanker or from the export facility, i.e. FSU/FPSO or production installation.

ESD 1	Termination of loading - shut down of cargo pumps - closure of valves - shuttle tanker remains connected
ESD 2	Termination of loading - shut down of cargo pumps - closure of valves - coupler claws open - release of chain stopper - activation of bow deluge system - tanker released from export facility

The advantages of having a bow loading system configured in the manner briefly described above are many and various, when compared to midships manifold systems. BLS units are so configured that the loading hose and the mooring line/chafe chain are connected to the tanker at virtually the same point onboard. This allows the tanker greater freedom to manoeuvre than does a midships manifold system with the mooring attachment on the bow, as is typical in a CALM buoy system. However, the installation of a deck hose extension from the midships manifold to the bow area overcomes that problem.

Another benefit is the provision of remote hydraulic release of the hose and chafe chain mooring connection. Although it is now generally recognised that the most effective method of release of hose and mooring is by remote ESD 2 actuation, there remain a number of tanker types, particularly earlier generation types, such as tanker A, that still require the chain stopper release mechanism to be actuated from a local control station on the forecastle. This means that personnel may be exposed to hazards in that area during an emergency.

Telemetry

Radio telemetry is the most effective safety feature in the entire cargo loading system. A telemetry system is generally installed at all offloading facilities. The principle on which it operates is that a series of interlock checks along the cargo transfer process have to be satisfied to enable cargo transfer to take place. Positive responses from all points in the transfer process establish a "Green Line".

Typically the important steps in the "Green Line" include the following:

- chain stopper locked
- loading hose in position
- manifold coupler closed
- manifold valve open
- inboard valve open

Should the "Green Line" be broken during loading the telemetry system will immediately activate a STOP signal to close down oil export from the export facility.

Telemetry signals are transmitted between the shuttle tanker and the export facility by UHF radio, frequencies being in the 450 to 469 MHz range. There are sufficient safety measures built into the telemetry systems to prevent unauthorised transmissions. The equipment comprises dual channel telemetry and radios with full system redundancy. The standard operational procedure is to perform a function test of the radio telemetry system before the offloading takes place, thus verifying the stop function on the cargo export pumps and the valve closures.

It is the general rule, although not statutorily enforceable, that the telemetry system must not be bypassed during cargo transfer operations. A fatal accident occurred in 1980 on a shuttle tanker when the telemetry system was bypassed. As a result the cargo pumps on the exporting platform continued to operate although both the mooring hawser and the loading hose had collapsed. A fire ensued that engulfed the bow of the tanker, killing the Master.

Clearly, a telemetry system is a safety critical element in the cargo transfer system. For continuous safe operations it should have in-built redundancy and be thoroughly reliable. Its operation should be controlled by effective management and strictly imposed procedures. As a general rule both conditions are met in the UK and Norwegian sectors. The experience of one major operator is that, since 1980, only a limited number of its 5000 offloadings have been interrupted as a result of equipment failure.

Tank Configurations

Cargo Tank Configurations
As can be seen from the tables there are various cargo tank configurations none of which is directly related to the close proximity aspects of this study.

Ballast Tank Configurations
As can be seen from the tables there are various ballast tank configurations none of which is directly related to the close proximity aspects of this study.

2.4.4 Main Engine Type

The average tanker or indeed any other type of ocean going vessel is generally propelled by a single main engine, connected to a fixed pitch propeller. This arrangement requires time to stop the engine and restart it in the other direction, in the offshore environment with much manoeuvring ahead and astern, the engine starting systems could not cope, therefore controllable pitch propellers have become universal.

There are a number of shuttle tankers fitted with medium speed Diesel engines driving a speed reduction gearbox once again to a single CPP. To bring shuttle tankers more into line with contemporary DP vessel thinking the most technologically advanced shuttle tankers are fitted with twin engines in separate engine rooms, generally allowing full redundancy of main propulsion in the fore and aft directions. Also the majority of the latest shuttle tankers seem to have settled on low speed small bore two stroke Diesel engines. There is some debate at present about reliability advantages of modern slow speed and medium speed Diesel engines, to the extent that it is concluded, that there is little difference between them. However, the medium speed engine has the added complication of a speed reducing gearbox.

2.4.5 Propulsion

Main Propulsion Types

As explained above CPPs are the preferred form of main propulsion on shuttle tankers. As with the tankers themselves propulsion has evolved through a number of stages. The early CPPs were designed for deep sea and had springs in the pitch operating mechanism to push the pitch to the full ahead position in the event of failure of the hydraulic system. While this is an excellent idea as a "get you home method" it has serious drawbacks for a shuttle tanker. If the hydraulic system was to fail when close behind a FPSO or an FSU, the tanker will drive off towards the station, a collision occurring before there is time to respond. To counteract this failure mode in the early CPP systems a trip was generally fitted to early shuttle tankers so as to stop the engine if, for any reason, the pitch wandered from astern to towards zero.

Later designs of CPP are fully hydraulic and are designed to fail as set or to zero pitch, some with the additional safeguard of tripping the main engine if pitch command and position feedback signals do not closely correspond.

There are some shuttle tankers fitted with twin medium speed engines both coupled to a single gearbox and propeller. In these cases it was perceived that Diesel engines are the least reliable items in the power train and the relatively more reliable gearbox/propeller did not need to be duplicated. The latest machinery configuration is for twin main engines and shafts, also with the ability to divide the power generation and distribution system into two, once again increasing redundancy.

The provision of two main propellers gives redundancy in propulsion systems, so that after the failure of one propulsion unit the other should remain intact. This is particularly relevant to the shuttle tankers since, to large extent, the most important axis to control is the fore and aft axis. With one main propeller remaining after a failure the tanker should have enough propulsion capability to prevent close quarters problems or collision with the export facility.

Experience shows, however, that although there are benefits of redundancy, there are also disadvantages in providing two main propellers located either side of the centre line. The main disadvantage is that when the tanker is in light condition problems can be caused by one of the propellers coming clear of the water when the tanker rolls and pitches in a seaway. This feature can result in manoeuvring difficulties at the most critical times, principally when in ballast and on final approach to the export facility.

Bow Propulsion Type

Tanker manoeuvrability is enhanced considerably by the installation of bow thrusters. The trend over the years has been to increase the number of bow thrusters on new buildings, thus providing extra redundancy in transverse propulsion. Redundancy is obtained by ensuring that the thrusters are independent of each other, so that the failure of any part of one thruster should not lead to the failure of the other thruster. Whereas the main propulsion is necessary for achieving wanted position in the fore and aft axis, transverse thrust at the bow is essential for close manoeuvring and heading control especially when in close proximity to the export facilities and at other critical times during the approach and departure.

Without bow thrusters it is very difficult to maintain the heading of a tanker, especially when in light condition, when attempting precise manoeuvring, when there is a sea running and in windy conditions. The bow of a tanker is normally raised above the level of the main deck. This gives considerable windage. The effects of the wind on the raised bow area can be considerable and cause rapid loss of heading if no counter thrust is applied from forward. There is insufficient turning moment from the main propulsion to control heading in these circumstances. Bow thrusters are typically tunnel thrusters and are controllable pitch. For maximum efficiency they are installed as far forward as possible, giving maximum turning moment.

The power consumed and the hp output of bow thrusters has tended to increase over the years and typical units now are rated at 2300hp. The increase in power of the thrusters has been influenced by a number of factors, viz., operational experience revealing lack of power in earlier units and the fact that the shuttle tankers are now moving into more environmentally hostile areas, such as Northern Norwegian waters and the Atlantic Frontier. In these areas more propulsion capacity is necessary to support offtake operations.

Stern Propulsion Type

Stern thrusters have been introduced to shuttle tankers to increase their manoeuvrability and redundancy. As in the case of bow thrusters, recently constructed tankers are generally equipped with more powerful stern propulsion units than earlier tankers. The thrust developed by a stern unit enhances a tanker's manoeuvring characteristics especially when in adverse environmental conditions of wind, sea and current and when subject to external lateral forces. As will be described later, the typical operating mode in shuttle tankers is to weathervane. The weathervane mode is intended to reduce the amount of transverse thrust. However, the weathervaning mode can result in a problem of dynamic interaction between the tanker and the export facility known as "fishtailing", described in Chapter 5. Part of the remedy for this problem is to manoeuvre the stern of the tanker in a transverse direction. This manoeuvre is helped if there is transverse thrust aft.

Rudder

Standard trading tankers are generally equipped with conventional rudders, that are designed to provide directional control when the ship is under way. More recent rudder technology has seen the development of "high lift" type units that are designed to provide a transverse thrust component. In this arrangement the wake of the propeller thrusts onto the face of the rudder and is deflected at an angle to cause transverse thrust. Effectively this type of unit can operate in lieu of or in support of stern thrusters. A tanker fitted with a "high lift" type rudder is more manoeuvrable than one fitted with a conventional rudder.

Typical Configurations

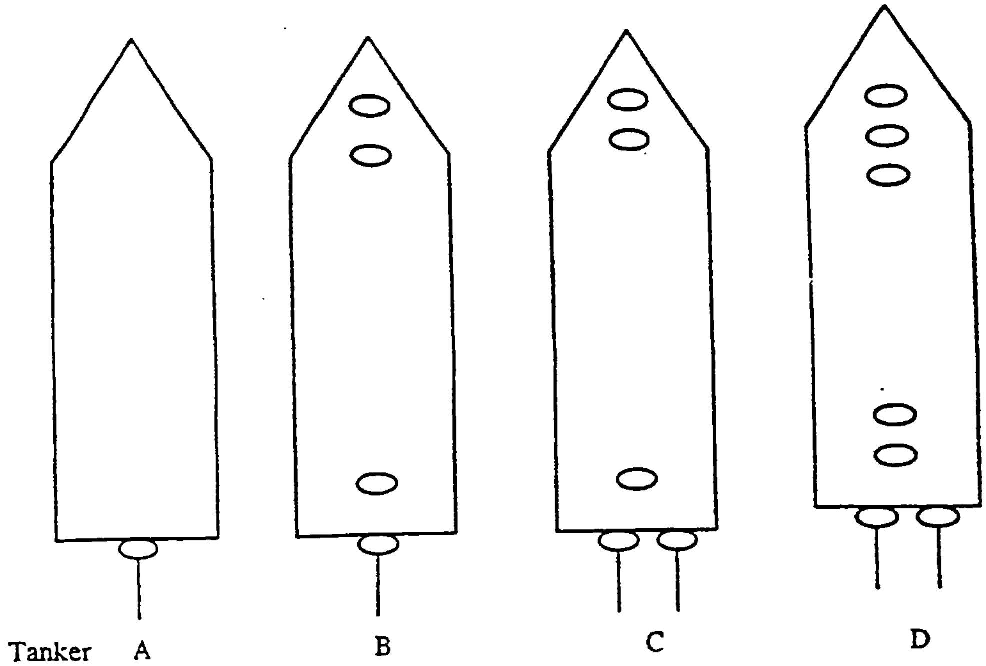


Fig 2-2 Typical Propulsion Configurations (see table 2.1)

2.4.6 Power

Power Generation

The most secure and effective way of ensuring power supply from generating plant is to install independent generating sets each capable of independent operation and, where necessary, with separation of auxiliaries, including fuel supplies, lubricating and cooling systems. This arrangement gives the maximum flexibility and power generation redundancy. This philosophy prevails in the design and operation of other types of DP ships that are engaged in high risk activities, such as DP diving ships, drilling rigs, crane and accommodation units.

A number of shuttle tankers are designed and operated in accordance with the above principles of providing maximum redundancy. However, the prevailing philosophy that underpins power generation in standard trading tankers is conceptually different in that it is largely based on using the main engine as a principal source of power. This philosophy has a major role to play in the design and operation of shuttle tankers. Practical demonstration of this is the installation of shaft generators and other types of power take offs that are commonly to be found on shuttle tankers. Although providing efficiency in terms of maximum utilisation of the main engine it does mean a reduction in redundancy. Where, for example, a tanker is equipped with a single main engine, as many are, the failure of that single main engine can have more extreme consequences than merely failure of the main propulsion. In worst case configurations the failure of a single main engine can also mean the loss of bow thrusters, engine auxiliaries and possibly, black out.

The power that is generated is increasingly high voltage, 6 or 6.6kV becoming the normal for newer Diesel electric tankers, such as tanker D in the tables. As can be seen from that table there is a considerable range of generating philosophies and configurations.

Tanker A has the most basic and nominally the least redundant configuration, since there are only three DGs. Other things being equal, tanker B's configuration has redundancy. There are five DGs on tanker B. Tanker C has a more modern and complex configuration but is fitted with a number of power offtakes from the propeller shafts, thus reducing the redundant features. Tanker D has the most flexible power generating system and is equipped with 4 identical DGs, producing 6.6kV, the DGs being split into two engine rooms.

Power Distribution
The most basic configuration is seen in tanker A where there is a single main 440V switchboard with one section and no bus-ties. This is a typical conventional tanker configuration. Increasingly the distribution systems have become more complex and the trend has been to design systems that have redundant features, such as bus-ties between separation sections of the main switchboard. This principle of redundancy is applied further to the distribution philosophy, resulting in the auxiliary systems and thrusters being supplied from different parts of the distribution network.

2.4.7 Control Location

The control location for the first shuttle tankers was in the bow control house. This is a specially constructed compartment far forward on the forecastle, affording a clear view of the adjacent export facility. The control house concept was based on the understanding that it was better to control the mooring, hook up, release, DP and visual monitoring of the entire offtake operation from forward than from another location, such as the navigating bridge. As seen from the tables the control location for the most recent tanker is on the navigating bridge whereas it is on the forecastle for the other generation tankers. This change of location is generally considered to be a risk reduction measure.

Where fitted, the bow control house is generally manned throughout the entire offtake operation, it not being normal to provide redundancy in control location. Typically there is only one DP control console and it is located in the bow house. Following a number of accident and incidents, see Chapter 3, resulting in human loss and structural damage to the bow house, improvement measures were taken across the shuttle tanker sector to enhance safety and provide additional personal protection. This resulted in the following enhancements; increased structural strength, automatic deluge systems, covered emergency escape routes, personal protective equipment (PPE) and the provision of a gas tight environment in the bow house.

The original concept that stemmed from a consideration of the advantages afforded by the bow location has largely been superseded by technical developments and by an acknowledgement that, notwithstanding the safety improvements, the bow location is not without appreciable hazard. It is now generally recognised that the navigating bridge is a safer location. Concerns that the monitoring facilities at the navigating bridge are inferior to the bow location have been largely overcome by improvements in CCTV. Systems are now being installed that consist of 24 remote colour cameras and selective monitoring on the navigating bridge.

2.4.8 DP Control and DP Systems

Detailed descriptions of DP shuttle tankers are given in Chapter 4. It is not the intention here to consider areas that are covered in greater depth in that chapter. The purpose of this subsection is to refer briefly to historical trends in DP shuttle tanker operations.

In the first instance there are many examples of shuttle tankers that have no DP capability at all. Reference was made in Chapter 1 to a number of export facilities specifically designed and equipped for non-DP tankers. A small number of offshore oil operators are convinced of the merits of non-DP shuttle tankers and are not inclined to alter their opinion on grounds of safety, environmental protection or productivity. It cannot be gainsaid that successful offtake operations continue to be carried out by non-DP tankers. However, the trend has been to equip shuttle tankers with increasingly advanced DP systems, incorporating redundancy in computers as well as control consoles.

2.4.9 Pump and Valve Configuration

As can be seen from the tables there are various pump and valve configurations none of which is directly related to the close proximity aspects of this study.

3. ACCIDENTS, INCIDENTS AND PERCEIVED HAZARDS

This chapter describes in brief some of the accidents and incidents that have been reported during the last 16 years or so of offtake tanker operations. During the preparation of this chapter it became clear that there is no single point of reference for the reporting and recording of such accidents and incidents. Those that occur in the UK sector are reported through the applicable statutory scheme, viz., to the HSE via the OIR/9A incident report system (now superseded by RIDDOR, 1995). Those occurring in the Norwegian sector are reported through the Norwegian regulatory reporting scheme.

There is a database in existence of ship/platform collision incidents that has been compiled from the above sources and from a number of other public and confidential sources. The database was created for the Health and Safety Executive (OSD) and has records of collisions back to 1985. This chapter provides an overview of the relevant records in that database. As will be clear from the presentation of the accident and incident information no attempt has been made to cross reference the details in the OSD's database with information gained directly from meetings with the oil companies.

Also this chapter considers analyses and conclusions drawn from a database of reported DP incidents. This database is administered by IMCA (International Marine Contractors Association). The results from the analyses provide statistical probabilities. Furthermore, a number of risk assessments carried out by duty holders in safety case preparation have been considered and this chapter contains an overview of results, principally a listing of statistical probabilities of tanker/offshore installation collisions.

Finally, this chapter deals qualitatively with the areas of concern that oil companies and tanker operators currently perceive to be of the greatest importance in respect of safety of offshore offtake operations. The details contained in this section are derived exclusively from the meetings with companies during the course of the project.

3.1 ACCIDENTS AND INCIDENTS

3.1.1 Overview

There is anecdotal and hearsay evidence to suggest that accident and incident rates involving DP and non-DP shuttle tankers in close proximity to export facilities may be higher than reported levels. This study sought to establish whether there was any substance behind this view by asking the operators of export facilities and tanker operators to indicate the severity and frequency of accidents and incidents occurring in their own areas of operation. The impression given by these industry representatives is that the level of accidents and incidents is not significant and that the control measures in place are adequate.

Eight oil operating companies were approached during the course of the study, three of which provided information on accidents and incidents that had occurred at their export facilities. Details are given in 3.1.2, 3.1.3 and 3.1.4.

In general, it is stated by the industry representatives involved in this project that areas of concern are being addressed. However, see section 3.6 for some stated concerns. The overall view is that risk areas are under control and that considerable progress continues to be made in implementing appropriate risk reduction measures. Certainly on the evidence of the relatively few number of accidents and incidents that came to light during the preparation of this report, there does not appear to be a significant problem in terms of accident/incident frequency or severity.

The following sub-sections give the recorded experiences of the three oil companies that gave information on accidents and incidents, viz., Company A - operator of a number of offshore fields, Company B - operator of one offshore field and, finally Company C - operator of one offshore field.

3.1.2 Oil Company A

The following accidents are the only ones of note to have been reported by one major oil operating company with interests in a number of different offshore fields in the years from 1980 to 1993. During that time more than 15,000 offtake operations were carried out at various types of facility, including SBM, ALP, STL and FSU/FPSO.

Accident 1 - 1980
A bow loading offtake tanker was moored by hawser to an ALP. The tanker was non-DP and there was tension on the hawser. Progressive hawser degradation resulted in the failure of the hawser in marginal weather conditions. The cargo loading hose was ripped off at the ALP's boom as the tanker was being forced off location. An additional complication was that the telemetry system had been bypassed, accordingly, oil continued to flow after the hawser and hose parted. A fire broke out in the tanker's bow area. It is thought that the fire was started by sparks from the chain stopper release mechanism igniting the spraying crude oil. The tanker suffered material damage and the master, who was in the bow house at the time, died from injuries received. This is the only recorded fatal accident in the period covered by this project. The oil spill was in the region of 3 to 4,000 barrels.

Accident 1 - Reactive Measures
Lessons were learned from this accident and a number of improvement measures have been adopted over the years as standard by the industry. These include the provision of deluge systems in the tanker bow area, A60 protection for the bow house, provision of pressurised atmosphere in the bow house, provision of enclosed escape routes from the bow house, procedural measures to ensure that the telemetry system remains fully operational throughout the duration of the offtake. Further risk reduction measures include the provision of quick disconnect dry break couplings on the loading hose and also, in some cases, automatic disconnect of the loading hose coupling on overpull. In addition the current philosophy of siting the control location away from the bow area and placing it on the navigating bridge is considered as an effective means of reducing the risk of exposure to personnel by physically separating them from the higher risks that are associated with the bow area.

Accidents 2, 3, 4 - 1981-83
There were three mooring hawser failures, two of which resulted in breakage of the loading hose. These incidents occurred during manual manoeuvring in marginal weather and were caused by a combination of cycling and relatively high mooring loads with unfavourable hawser and thimble design. These two incidents caused only minor oil spills, each of less than 150 barrels.

Accidents 2, 3, 4 - Reactive Measures
The successful development of the DP shuttle tanker concept has reduced the risks associated with hawser operations. Currently the majority of offshore loadings are carried out on DP, although the hawser remains attached. There is considerable weight of informed opinion that is in favour of hawserless DP shuttle tanker operations. As can be seen from Chapter 4, there have been significant developments in the capability and reliability of DP shuttle tankers. Additionally improvements have been carried out to hawser and thimble design. For example, it is now standard to fit a weak link in the chain section of the mooring system.

Accidents 5, 6, 7, 8 - 1984-93
There were four contacts between tankers and loading buoys, including one caused by a breakdown in the control system for the CPP, two resulted from DP failure and one for which there was no clearly stated reason. According to the field operator it is likely that the last accident was caused by human error.

Accidents 5, 6, 7, 8 - Reactive Measures
Considerable efforts have been made to improve the reliability of CPPs so that the failure of a CPP should not have serious consequences. Refer to Chapter 4 for the section on CPPs. Additionally as indicated above in the measures taken following accidents 2, 3, and 4 there continues to be significant development in the capability of DP shuttle tankers, thus reducing the likelihood of DP failure. Lastly, the problem of human error is always present. Some improvements have and continue to be made in this area. These are also outlined in Chapter 4.

3.1.3 Oil Company B

The first is an incident rather than an accident is the only one of note involving an offtake tanker to have been reported in the 3½ year life span (1993-1997) of a small field where export is carried out via stern loading from the custom built FPSO. In that time 98 offtakes had been carried out. The second accident is related to hose equipment failures.

Accident 9
On the approach of the offtake tanker to the FPSO the pre-connection checks on the tanker revealed a problem with pitch control of the main CCP. This resulted in abandonment of the approach and return of the tanker to port for repairs.

Accident 9 - Reactive Measures
The failure of the CPP was detected during the pre-connection checks. Comprehensive checking and equipment testing in the approach stages have become standard for all types of offtake tanker. Additionally as indicated in 3.1.2 above considerable efforts have been made to improve the reliability of CPPs.

Accident 10
The FPSO was initially fitted with a breakaway coupling on a 120 metre long hose string. On the occasion of the first cargo export the breakaway coupling parted during the deployment phase. As a result the breakaway coupling was dismantled since the field operator considered that there were sufficient measures to safeguard the hose from over tension failure, in particular, DP control of tanker positioning, hawser connection providing alternative means of maintaining tanker position and protecting the hose, remote hose quick release and local hydraulic release.

Accident 10 - Reactive Measures
The reactive measures taken were localised and have little significance for the industry as a whole.

3.1.4 Oil Company C

There is only one accident that occurred early on in the life of the field. The field started production in 1983 and in that time there have been in the region of 600 cargo offtakes.

Accident 11
Collision between the export tanker and the adjacent support vessel. The non-DP tanker was approaching the pick up point of the messenger line, which was held by the support vessel. The tanker had a standard propulsion and control system. It was equipped with a single main propeller and no thrusters. The approach was being carried out in manual control. At the time of the collision the environmental conditions were marginal. There was a shift of wind at a critical phase in the approach and this caused the bow of the tanker to bear down on to the support vessel resulting in collision. There were no personal casualties or injuries. However, both the tanker and the support vessel suffered structural damage.

Accident 11 - Reactive Measures
After the collision the oil company reassessed the use of standard tanker types at their single point offshore loading facility. Although more economical to operate it was apparent that the risks associated with their continued operation at the field were significant. As a result the company decided to introduce DP shuttle tankers equipped with transverse bow thruster capability, thereby increasing the manoeuvrability of the tanker in close proximity situations.

3.2 OSD SHIP/PLATFORM COLLISION DATABASE

3.2.1 Overview

A summary of the data recorded in the HSE's database indicates that over the period 1975 to 1995 there were 460 ship/platform collision incidents in the UK sector. Of that number 301 were with supply vessels, 70 with standby vessels, while the remaining were either with unspecified vessel types, 30 incidents, or, were with other attendant vessels, 55 incidents. The HSE study broke down the other attendant vessels into specific types and identified that there were 4 collisions involving offtake tankers and offshore export facilities, i.e. 0.87% of the total. The following listings provide brief details of the recorded collisions.

3.2.2 Tanker/Platform Collision Listings - 1975-1995

November 1984 - Accident A
A 41,728grt offtake tanker collided with the loading buoy at a Northern location. Cause of the incident was failure of the engine control system during approach phase.

November 1988 - Accident B
A 43,622grt offtake tanker had a collision incident at a Northern location. Neither damage to the installation was reported, nor cause of the collision.

May 1989 - Accident C
An offtake tanker collided with an SPM during mooring operations at a Northern location. This was caused by a misjudgement.

September 1992 - Accident D
An offtake tanker collided with an installation during the offtake phase of the operation. The accident was caused by failure of the DP control system.

3.2.3 Discussion

The accident information that was used to compile the database comes principally from events in the UK sector. It is noted that the database does not hold information on incidents or near misses that are essential elements in a proactive safety and hazard management system. It is not known what the accident/incident ratio might be. Also, on the basis of the extremely small number of reported accidents in the database it is impossible to make an informed and reasonably accurate judgement on the level of risk.

3.3 IMCA - DP RISK ANALYSIS

3.3.1 Overview

A data base has been compiled of incidents involving DP vessels. The data base is held by the marine division of IMCA (International Marine Contractors Association) and holds information on DP incidents from 1980 to the present day. A risk analysis was conducted on the incident data and a report issued in October 1994. The specific purpose of the risk analysis was to address diving operations operating in close proximity to offshore installations. The background to the risk analysis was the statutory requirement, under the safety case regulations, for operators of offshore installations to reduce risks from major accidents to ALARP, viz., a level which is as low as is reasonably practicable.

Although the risk analysis was carried out specifically to address diving operation it is stated in the risk analysis report that the results have a relevance to all DP vessels operating close to offshore installations. Inevitably this includes DP shuttle tankers. As far as is known none of the reported DP incidents used in the analysis originated from a DP shuttle tanker. All of the data used came from the DP incident reporting scheme administered by IMCA. There is no comparable forum for DP shuttle tanker sector, although it is understood that the tanker owners (INTERTANKO) have formed a shuttle tanker section that can conceivably undertake the same kind of activity as is currently undertaken by IMCA on behalf of other DP vessel owners.

3.3.2 DP Incident Reporting Scheme

Population
The scheme is open to members of IMCA. Currently there are approximately 29 companies and more than 70 DP vessels. There is a wide range of DP vessel types, including but not limited to the following; diving ships, ROV support, drilling, floating offshore production installations, accommodation units, heavy lift crane and construction barges, survey and pipelay barges. There are no geographical limits; DP incidents being reported from all over the world, although the majority are in NW European waters.

DP Incident Report Form

The reporting medium is a DP incident report form that requires specific details to be provided of the DP configuration, the operation and the environmental conditions. The form is available on all DP vessels and it should be completed if the vessel experiences a DP incident. IMCA consider a DP incident to be a loss of position that occurs to the surprise of the DP operator.

DP Incident Analysis

The DP incident report forms are sent from the vessels to their respective companies and are then passed on to the Marine Division of IMCA for analysis. A single page analysis report is prepared for each incident. The analysis report identifies the basic elements of the incident and presents them in a block diagrammatic flowchart. The flowchart describes the background circumstances, the initiating event, the immediate and longer term consequences and the actions taken on board in response to the incident. In addition, main and secondary causes are identified. The causes are sub-divided into the following categories;

1. Design
2. Procedures
3. Computers
4. References
5. Thrusters
6. Electrical
7. Human Error
8. Testing/QA

Furthermore the analysis requires that the incidents are categorised according to severity into the following three groups;

1. Loss of Position	major consequences
2. Loss of Position	minor consequences
3. Loss of Redundancy	downtime consequences

The results from the analyses are published by IMCA and are distributed to all member companies and vessels. In most years the results are also presented at the annual IMCA DP seminar. Confidentiality is maintained throughout, to the extent that it should not be possible to identify where the incident took place or the identity of the ship or company from the flowchart. This is intended to encourage the reporting of incidents and to avoid the potentially harmful commercial consequences that might arise if individual vessels or companies were to be identified.

Reporting Patterns

The patterns of reporting indicate that companies and vessels have different levels of commitment to the scheme. For example, the data for 1995 show that of a total population of more than 70 vessels, only 20 reported one or more DP incidents. The conclusion drawn from that statistic is that between 70% and 75% of DP vessels either do not have DP incidents or are not reporting them. Principally as a result of the apparent inconsistent levels of reporting, IMCA acknowledge that the recorded incident rate is likely to be somewhat less than the actual incident rate. It is suspected that some owners, masters and DP operators remain reluctant to report things that go wrong.

3.3.3 IMCA DP Risk Analysis Results

Results of Risk Analysis

According to the data used for the analysis, in the period 1980-92 there were 224 recorded DP incidents, of which 23 were recorded as resulting in collision with the adjacent installation. That represents a total of 10.3% of the total number of incidents. Calculations have been performed on the data by IMCA for that period and updated with new incident information from IMCA and Statoil to cover the period to late 1996.

These calculations estimate that the probability of impact with an offshore installation for a typical DP ship following DP drive off is currently in the order of 1.0×10^{-2} per year. However, it is acknowledged by IMCA that the data used in the risk analysis includes incidents that occurred in the early phases of DP operations and may not reflect the current situation. The IMCA report considers that modern DP systems, in particular with more reliable position reference systems and computer redundancy, are likely to have a lower failure rate. Therefore the probability of collision would now be in the order of 2.0×10^{-3} per year. Also the report estimates that the probability of collision causing major damage to be in the region of 5.4×10^{-4} per year.

In addition, the report concludes that the estimated annual collision frequency following drift off is in the region of 5.3×10^{-4}. It is further estimated that typical drift velocity would be approximately 0.3 m/s and that, therefore, the resulting damage would be negligible.

For the purposes of clarification the risk analysis used the following definitions;

Drive Off where the ship is driven off position by its own thrusters because the DP control system believes the ship to be out of position.

Drift Off where the ship drifts off because of insufficient thruster capacity or because DP control system believes the ship to be keeping position.

Discussion of IMCA Results and Relevance to DP Shuttle Tankers

Firstly, there are differences in exposure rates, this being the number of hours in a year that the vessel spends on DP control. Although each IMCA DP vessel has a different exposure rate, it is not unreasonable to suggest that IMCA vessels do tend to have a greater aggregate of hours on DP than DP shuttle tankers. For example, a conservative estimate of a typical exposure rate for a DP diving ship would be in the region of 4,000 hours per annum, i.e. approximately 165 days at 24 hours per day, whereas a DP shuttle tanker could reasonably be expected to have an exposure rate of 1,200 hours per annum. This is based on a conservative estimate of 50 offtakes per year, each of 24 hours duration. The conclusion drawn from this is that the DP incident rate for shuttle tankers should be less than for the other types of DP vessels that are involved in the IMCA scheme.

Secondly, there are also other differences that are related to quality control elements of the DP system. For example, typical IMCA DP vessels are subjected to greater levels of DP trials and other DP verification procedures than are DP shuttle tankers. They are also generally equipped with more redundant features than DP shuttle tankers, all of which is aimed at providing greater reliability and DP capability. Given the lack of specific detailed information it is not possible to give an accurate indication of the impact that these differences will have on the frequency of the DP incident rate, other than to suggest that it would tend to produce less favourable figures.

3.4 OTHER STATISTICAL SOURCES

3.4.1 Overview

Other statistical calculations have been carried out on the risks of collision between offtake tankers and adjacent export facilities. For the most part the calculations have been carried out as part of the safety case requirement for the effective management of major accident hazards and for the reduction of risk to the level of ALARP. The figures gathered during this project indicate that there are considerable differences in the quantified risks. The table below gives an overview of a range of values for a number of different export facilities. In keeping with the project's commitment to preserving the anonymity of the companies involved in this project, neither the offshore installations nor the oil companies have been identified. For the purposes of clarification the tabulated values are extracts from installation specific safety cases that have successfully gone through the HSE's acceptance process.

TYPICAL RANGE OF STATISTICAL PROBABILITIES OF COLLISION BETWEEN DP OFFTAKE TANKER AND OFFSHORE EXPORT FACILITY

Sample Export Facilities	Annual Probability of Impact Causing Slight Damage	Annual Probability of Impact Causing Severe Damage
FPSO 1	2×10^{-3}	5.4×10^{-4}
FPSO 2	1.9×10^{-4} *	
FPSO 3		$8.16 X 10^{-5}$
FSU 1	1.5×10^{-2}	
SPM 1		$2.7 X 10^{-5}$
SPM 2	1.7×10^{-3}	

Table 3.1

*includes all ships, viz., support vessels, shuttle tankers, passing traffic.

3.4.2 Discussion

It is not possible to make a straight comparison of the figures above without taking account of the various assumptions and parameters that have been used to support each original calculation. Each facility is different. For example there are differences in the number of cargo offtakes per year. Other things being equal (OTBE), more offtakes mean more risk.

In addition, proper account should be taken of the additional control measures that are implemented in respect of each facility and shuttle tanker. This will include such elements as separation distance, quality and verification of shuttle tanker procedures, manning and training, quality, redundancy and verification of DP systems and procedures, emergency preparedness in the event of certain failure modes, (e.g. operator action following pitch control failures).

A proper evaluation of all items above should result in a more accurate determination of risk of collision. For example, the risks associated with each offtake operation are different and depend on a variety of factors, in particular, the quality and level of redundancy of the offtake tanker, so that where two tankers serve the same export facility, then one will invariably present a greater risk of collision than the other. The extension of this logic is to find the tanker with the least risk factor. This is considered in Chapter 5.

AREAS OF PERCEIVED HAZARD

3.6.1 Overview

During the preparation of this report a number of meetings were held with operators of offshore export facilities and with owners and operators of DP shuttle tankers. The meetings were wide ranging in content and, among other things, the discussions considered, in a qualitative manner, the current concerns of the industry.

3.6.2 Tabulated Results

The following table provides a synopsis of the current concerns.

CATEGORISATION OF AREAS OF PERCEIVED HAZARD

Category	Comments	Criticality Rating
Tanker Positioning and Control	1. Operation and reliability of position reference systems for DP shuttle tankers. 2. Drift movement of NUC tankers following all power loss. 3. Change over from auto to manual control in emergency situations	6
Tanker Human Factors	4. Manning of control spaces, inc. DP control locations, engine room. 5. Cultural differences. 6. Training, familiarisation and competence of tanker crews.	5
Dynamic Interaction	7. "Fish-tailing" 8. "Surging"	4
Tanker Propulsion	9. Operation of CCP thrusters and failure modes that may result in a thruster failing to maximum thrust. 10. Potential failures of main propulsion.	2
Operational Management	11. Commercial pressure in decisions relating to offtake operations, especially in adverse environmental conditions.	2
Environmental Preparation	12. WX and environmental monitoring, in particular accurate measurement of Hs and surface currents, especially in recent development areas, such as the Atlantic Frontier.	2
Support Vessel	13. Support vessel operations and training and familiarisation of support vessel crews	1
Tanker Power Generation	14. Use of heavy fuel oil in main engine and power generation plant on DP shuttle tankers.	1

Table 3.2

The above table has been compiled from the responses made by the representatives of the industry to the question "What area or areas of shuttle tanker operations cause the greatest concern in terms of safety and/or environmental pollution and how are they best addressed?" It is important to point out that no guidance or further leading questions were given at this stage of the meetings and that, therefore, the responses are totally voluntary and self generating. Brief discussions were held on the current areas of concern and note was taken of the responses, which were later categorised and tabulated in the form shown above. The responses were counted and a criticality rating was given to each category. The criticality rating is based merely on the number of responses in each category. The comments column contains specific details of each category. The following sub-sections expand briefly on specific details.

3.6.3 Specific Areas of Concern

Operation and Reliability of Position Reference Systems

This is dealt with in Chapter 4 of this report, which gives considerable detail on the various elements that comprise a DP system. Position reference system (PRS) problems are potentially the most troublesome of all systems in a DP system. In the analyses of DP incidents carried out by IMCA, the percentage caused by PRS failure is consistently high. For example the analysis of DP incidents occurring in 1995 concludes that 13% of all DP incidents were caused by PRS failure. The figures for 1993 were significantly worse, where of all DP incidents analysed, 47% were considered to be caused by PRS failure.

From an operational perspective it is better to have a number of position references on line simultaneously. This gives redundancy, so that failure of one position reference should not lead to a position drop out. There is inconsistency in the DP sector as far as the number of on-line position references is concerned. The typical arrangement for DP diving operations and for most other critical DP operations is for a minimum of three PRS to be on-line. However, three is not typical of DP shuttle tanker operations. It is more common to operate with two or even with one PRS. For example, one major oil company that operates a number of DP shuttle tanker export facilities in the North Sea requires there to be two PRS available and on line before final approach is made to the export facility. If there is a failure of one of the PRS during the offtake operation, this requires the master to reassess the situation but does not require disconnection.

Operating with only two PRS or, even one, means that the reliability and accuracy of the on-line systems must be adequate, since there is little or no redundancy. This has proved to be a problem in the past for DP shuttle tanker operations. The most reliable PRS and the one which has the greatest confidence rating of all in the entire DP sector is the vertical taut wire. In this system a weight is placed on the seabed and a small diameter wire under tension rises vertically to the surface from the weight to a inclinometer sensor on the ship. The sensor is able to detect small changes in the vertical angle of the wire. As the ship moves in the fore/aft and port/stbd axes so the taut wire changes its vertical angle at the inclinometer. These angular changes are transformed into horizontal distances and give position information that is transmitted to the DP control system.

Taut wires are used extensively elsewhere, especially in the DP diving sector and DP drilling sector, where the principal objective is to remain on location over a fixed geographical target. However, DP shuttle tankers do not operate in accordance with that philosophy and therefore the taut wire is unsuitable. The most typical operating mode of DP shuttle tankers is to remain on location in relation to a point that is not fixed in space. That point is normally the loading point located on the stern of a weathervaning FSU/FPSO. Therefore the positioning of the DP shuttle tanker is based more on relative positioning rather than absolute positioning. See Chapter 5 for further details.

The PRS that are of particular use to DP shuttle tankers and to relative modes of operation are DGPS/DARPS, Artemis, Fanbeam Laser and HPR. All of these are considered in greater detail in Chapter 4. As will be seen from Chapter 4, considerable progress is being made to improve the reliability and accuracy of these systems for DP shuttle tanker use. This is particularly the case with DGPS/DARPS.

Drift Movements of NUC Tankers
This causes concern when risk assessments are being carried out of worst case scenarios, in particular where a tanker may be totally incapacitated without propulsion and with no control of its movements. Many export facilities are located in congested development areas where there are other offshore installations in the vicinity, typically 1.5 to 2.5km distant, such as production platforms, anchored drilling rigs and accommodation units. This worst case scenario does present a risk of collision. Total failure of the tanker's propulsion would mean that, before a support vessel managed to get it under tow, its movement would be totally at the mercy of the external environment, i.e. wind, current and waves.

Studies have been undertaken on the probable drift movement of tankers under different environmental conditions and under different conditions of loading. One major oil company that operates a number of export facilities requires the tankers that it uses to carry out a series of drift tests to establish likely patterns of movement in the event of a total loss of power. The drift values are then taken into consideration when establishing the operating parameters.

There is considerable potential for serious damage in this worst case scenario. Appropriate risk reduction measures are in place at a number of export facilities, the following being the most frequently applied. Sector restrictions are placed on the tanker, so that if it lies up weather of a surface installation within a predetermined sector, then a support vessel with towing capability is placed on immediate close standby and, where the tanker is directly up weather, is connected to the tanker.

Further risk reduction measures include the use of DP shuttle tankers with enhanced levels of redundancy, such as twin engine and twin main propulsion systems. OTBE the use of better equipped tankers should result in a reduction of risk, in that they are less likely to suffer propulsion and/or control loss. Details of typical tanker propulsion arrangements are given in the descriptive section of Chapter 2 and the classification and redundancy characteristics of DP systems are given in Chapter 4.

Change Over From Auto to Manual Control
As in the case above this problem area is also associated with a worst case scenario, which occurs when the tanker is in close proximity to an FSU/FPSO, possibly at a nominal 60 metres horizontal separation. The scenario is that the tanker drives ahead and is about to come into contact with the stern of the FSU/FPSO. There are a number of possible causes for the tanker to drive ahead. For example, it may be as a result of a fault in the main propulsion system which causes a CPP to drive ahead uncontrollably. It may be caused by incorrect data from a PRS. Or, it may be as a result of "surging", i.e. a phenomenon caused by the dynamic interaction between the tanker and the FSU/FPSO, see Chapter 5 for fuller details of "surging".

The obvious problem here is that excessive forward motion of the tanker might result in collision with the stern of the FSU/FPSO. The risk reduction measures that may be considered viable here include all of those that would reduce the probability of the worst case scenario occurring in the first place. Taking each causal factor in turn such measures would include ensuring that no single failure mode could result in the CPP going full ahead, using a tanker with twin main propulsion units, ensuring that sufficient PRS are in use and also ensuring that there is an adequate initial horizontal separation distance between the tanker and the export facility to avoid a close quarters situation.

However, even if the above risk reduction measures were taken, it is essential to consider how the person in control of the DP console should react if all of these measures failed and collision with export facility was imminent. The normal emergency procedure for other types of DP ship, such as a DP diving vessel 15 metres distant from an installation, is for the DP operator to assume manual control and to attempt to manoeuvre the ship away from the installation thus avoiding collision. This strategy is likely to be successful for DP diving ships that are invariably side on to the installation, where the transverse momentum of the ship and separation distance are low enough for a counter movement to be successful. However, the situation is radically different for a DP shuttle tanker that is head on to the stern of the FSU/FPSO. The momentum built up over a distance of 60 metres is considerable and as a result the counter movement required to stop and then reverse the direction of the ship over that short distance is even greater. As a result the strategy of executing a counter astern movement is most likely to fail for a DP shuttle tanker. The question arises as to which manual manoeuvre is most likely to be the most successful. Emergency stop of the propulsion is not likely to prevent a collision, since there is no counter movement and there is too much momentum for an emergency stop to have any effect. However, an immediate hard over rudder movement, although not likely to prevent collision, should help in limiting the collision damage.

This issue of how to deal with emergencies is further complicated by problems associated with identifying when the DP shuttle tanker is in an emergency situation. There are examples when single engine DP shuttle tankers in close proximity to an FSU/FPSO, go from full ahead to full astern during periods of dynamic interaction. Failure of the main propulsion during an ahead or an astern movement could have serious consequences. If going ahead the failure would inevitably result in a collision. If going astern the failure is also likely to result in collision, since the continued astern movement would result in the hawser coming under tension. The recoil action caused by the stored energy in the hawser under tension would then tend to catapult the tanker back in towards the FSU/FPSO.

Manning of Control Locations

Since they are classed as deep sea trading vessels a number of DP shuttle tankers operate in line with deep sea manning standards. For instance, the engine room may have a class notation, UMS (unmanned machinery space), permitting an unmanned engine room at all times when at sea, including during the offtake period. Although strictly in line with national and classification society requirements there remains the concern that the response time required for an engineer to attend a problem in the engine room, such as a fire, is likely to be considerably longer than for an engineer on watch in the engine room. It is also likely that a machinery malfunction or a DP event in the engine room could have escalated considerably in the time it takes an engineer to get to and tackle the problem.

This feature of engine room manning is not shared by other types of ship operating in close proximity to offshore installations. For example, typical arrangements for DP diving ships, standby boats, survey ships and also supply boats are to ensure that there is a qualified engineer on watch in the engine room when the ship is within the 500 metre zone of an offshore installation. This standard of manning is not necessarily repeated on a DP shuttle tanker, even although it might be only a 50 or 60 metres away from the FSU/FPSO and the associated risks greater by several magnitudes. It would be reasonable to suggest that similar standards of permanent watchkeeping be employed on DP shuttle tankers.

Similar considerations apply to the manning of the DP control console. The standard manning requirement for other types of DP operation is for the competent person who is in charge of the DP operation, viz., the on-line DP operator, to be in close attendance at the DP console. Effectively this means that the DP console is under constant human surveillance. There are advantages in this. For example, such close monitoring of the operation of the DP system ensures that the DP operator is adequately prepared if required to intervene in the event of a problem. This is a standard principle in other DP operations. Typical arrangements are for two DP watchkeepers to be on watch in the DP control area at any one time, one being in nominal control at the console while the other is carrying out some other related duties. To prevent the onset of tedium that may result in loss of concentration the watchkeepers normally change over roles every hour.

It is also acknowledged in DP operating circles, that there are many occasions when DP related problems are detected first by the DP operator and that effective counter measures are taken by the DP operator before the DP system.

It appears that the typical arrangement for DP shuttle tankers is to use the DP control system as an alarm system, thus cutting back on the console monitoring and potentially losing the advantages that are clearly associated with effective DP watchkeeping.

Cultural Differences

There are various manifestations of the cultural differences that exist between DP shuttle tanker operations and other types of DP operations. A number have been raised in the preceding paragraphs, in particular the manning of control locations. The cultural differences are not restricted to shipboard operational situations but extend to the overall management and control of the DP shuttle tanker sector. Different standards prevail.

Example 1 - The standards of DP verification, testing and trials generally required by the DP shuttle tanker sector appear to be less comprehensive than for other types of DP ships. In particular, the IMO guidelines relating to ships with DP systems state that all DP ships should be undergo a series of ship specific tests and checks including annual trials that will verify the ship's continued ability to withstand single point failures. This has been a standard practice for DP ships whose owners are members of IMCA, (formerly DPVOA). For them this requires the preparation of a DP FMEA, followed by a set of proving trials, that in turn is followed by a set of annual DP trials. Although standard practice elsewhere, it is not fully implemented in the DP shuttle tanker sector. It appears that most DP shuttle tankers have been subjected to a DP FMEA. However, it also appears that the FMEA documents remain in theoretical form without the benefit of proving trials and also without the annual trials that have become a regular feature of other types of DP ships. As a result the FMEAs have not been verified. Therefore there may be single point failures in the DP systems that have not been detected. It is only by proving trials that the DP FMEA can become a fully viable analysis.

Training, Familiarisation and Competence of DP Shuttle Tanker Crews
This aspect is dealt with in considerable detail in Chapter 4 of the report. There are two strands to this concern, viz., issues related to competency and certification and also issues related to ship specific familiarisation and hands on experience.

As far as competency and certification issues are concerned it is apparent that the training centres, courses and syllabi are generally geared up for DP ship types other than DP shuttle tankers. As will be seen from the contents of Chapter 4 the situation is improving and more recognition is being taken of the DP shuttle tanker sector. More shuttle tanker specific courses are being developed, more simulator hardware is being installed and the tanker masters and navigating officers are getting effective training. Yet, it is clear that the system caters best for the majority and that means DP operators of dive support ships, drilling units, cable layers, etc.

The second and perhaps the more important strand in this concern relates to the way in which on a large number of DP shuttle tankers, the hands on operation of the DP system remains the preserve of the master. It is a common feature of DP shuttle tanker bridge management that the master does not delegate DP operational control to other officers and that, frequently, he remains on watch and in charge of the DP console throughout the entire offtake, lasting typically from 18 to 36 hours. This is considered by a number of those who participated in the project as being out of step with current principles of effective bridge management, if not also being inherently hazardous. Operating such a system does not give the master adequate rest.

It is widely acknowledged in the shipping industry that the most effective methods of managing human resources in critical activities such as in navigation and manoeuvring are based on good team work. This principle is the central tenet in the successful bridge resource management (BRM) courses that are now widespread in shipping. Effective team work means that members of the team are able to take over some other person's role not only in the event of necessity but also in normal operating situations. It is apparent that these principles are not to the fore in the operation of DP shuttle tankers.

Fish Tailing and Surging
These concerns are considered in detail in Chapter 5.

Operation of CPP Thrusters and Failure Modes
The operation and failure modes of CPP thrusters are considered in detail in Chapter 4. During the meetings held in the preparation of this report an example was given of a failure mode of a CPP thruster that resulted in the unit going to full ahead. The CPP was a main propulsion unit. The command signal to the thruster electronic control unit (ECU) was ±10V. The signal from the ECU to the CPP was 4-20mA. Therefore, the failure of the 10V signal resulted in the ECU signal failing to full in one direction, either full ahead or full astern. The effects of this failure mode lay undetected in the system until discovered during an FMEA.

Potential Failure Modes of Main Propulsion Systems
As above.

Pressure to Continue Production
It is inevitable that this perspective is considered in relation to DP shuttle tanker operations. Although commercial considerations should not be the pre-eminent factor in the operational

decision making process it is nonetheless apparent that there are occasions when additional commercial pressures are brought to bear on the senior personnel involved in the operation. This is seen in the following example.

"Ullage levels on a FPSO are fast disappearing because of continued production. The environmental conditions are deteriorating. The installation asks the tanker to approach, connect up and load only a few hours worth of cargo under explanation that this would relieve the pressure on the installation and provide sufficient ullage to enable full production to continue for a few more days, by which time the environmental conditions should have improved."

This is a realistic scenario and gives rise to occasions when both the offshore installation manager (OIM) and the tanker master feel under pressure to attempt an operation in conditions that are perhaps marginal and deteriorating.

This scenario is widely acknowledged to be representative of actual experience and appropriate risk reduction measures have been implemented in some management systems. Such measures are normally concerned with ensuring that the decision to begin an approach requires joint agreement between the tanker master and the OIM. It is also a feature of such decision making processes that it only requires one of them to decide to disconnect. Whether these measures alone are sufficient to overcome the problem is questionable.

Environmental Preparation

After many years of successful shuttle tanker operations in the North Sea the concept is currently under development in more extreme environments, in particular the Atlantic Frontier, inc. west of Shetland and offshore Canada. The environmental conditions experienced in the North Sea are well documented and their effects on the shuttle tanker operations are generally well understood and predictable. However, although considerable research work and information gathering has been carried out in the newly emerging areas to determine the actual environmental profile, the effects on the shuttle tanker operation are not entirely known.

For example it is known that the environmental profile for the sea area to the West of Shetland is somewhat different to that of the North Sea. Significant features are that swell, wind, wave and current are frequently from different directions and that this combination of forces is likely to have an adverse effect on the manoeuvrability and control of the shuttle tanker as well as on the dynamic interactions between the FSU/FPSO and the shuttle tanker.

It is generally accepted that one of the effects of the harsher environmental conditions will be an increase in downtime and more interruptions to the entire loading cycle than currently experienced in the North Sea. It is this troubled area that causes some concern. Appropriate risk reduction measures include the following; effective management/procedural controls and accurate forecasting of environmental conditions, increased separation distance and increased technical specification.

Support Vessel Operations, inc. Training, Familiarisation of Support Vessel Crews

It is generally accepted that a support vessel is in attendance for the duration of the offtake. Apart from a few exceptions its assistance is invariably required at the connection phase and the support vessel remains in relative close proximity to the shuttle tanker during the course of the offtake. The support vessel is on standby to undertake emergency towing duties in the event of a major problem with the tanker.

For many offshore safety case (OSC) duty holders the close attendance of the support vessel is considered as a major risk reduction measure. However the ability of the support vessel to fulfil its emergency role may be called into question because of a number of factors, inc. the suitability of the support vessel to undertake emergency towing operations in adverse environmental conditions, the training and capability of the crews of the support vessel to carry out such activities. There are, for example, comprehensive guidelines in the UK that are used to assess the suitability of standby vessels, yet there are no comparable guidelines for the assessment of suitability of support vessels, this being left to the operators to decide.

Use of Heavy Fuel
Where other DP ship types have, to a large extent, replaced heavy oil (HO) with Diesel oil (DO) systems, most DP shuttle tankers still use HO. It is a widely held view that a failure in a HO system is more liable to result in subsequent failure of standby machinery to start, principally because of the additional heating requirements for HO, than with a DO system. The associated risks have been accepted by other DP ship types and appropriate modifications carried out. Whereas generally, in other areas of DP operations, the risks of fuel associated problems have been assessed and measures taken to reduce the level of risk to ALARP, it does not appear the same exercise has been undertaken in the case of DP shuttle tankers.

3.7 CONCLUSION

One of the most important points to emerge from this chapter is that the reporting and recording of DP shuttle tanker accidents and incidents are neither organised nor administered in a manner that is capable of bringing maximum benefit to the participants in the industry. For instance, it appears that UK duty holders experienced difficulties in finding appropriate industry wide data in carrying out safety case risk assessments. It is also likely that there is under reporting, particularly of DP shuttle tanker incidents.

There are considerable benefits to be gained from a sector specific accident and incident reporting scheme. The benefits are apparent in the DP incident reporting scheme administered by IMCA. A similar scheme for the shuttle tanker sector would assist in broadening the knowledge base of those involved in the sector.

4. DP SHUTTLE TANKERS

DP shuttle tankers make up the largest group of offshore offtake tankers in operation in North West Europe. As indicated in Chapter 2 their numbers have increased markedly over the last two decades and there are now in excess of twenty operating on the North West European Continental Shelf, principally in Norwegian and UK waters. The technical complexity of DP tankers varies considerably, generally the newest tankers being fitted with the most advanced control systems and greatest levels of redundancy.

Considerable progress has been made in recent years to improve the reliability and effectiveness of DP control systems in general and many of the improvements have been applied to the DP shuttle tanker fleet as well as to other ship types in the large and diverse DP fleet. This chapter provides an overview of past and current improvements that have been made in DP control systems and in component parts. It also describes the main problems associated with DP systems, equipment and subsystems. This chapter also provides an overview of the management of DP ships, in particular, the mechanisms that are available to ensure fitness for purpose to carry out DP operations safely. In addition the chapter describes the ways in which the DP shuttle tanker sector responds to these mechanisms and assesses industry practice against the available mechanisms.

4.1 DYNAMIC POSITIONING - DESCRIPTION

4.1.1 Historical Development

DP was first used in the early 1960s. Early applications were used on drillships, dive support, coring and cable laying vessels. The early systems were generally simplex, consisting of a single analogue computer, single position reference system and single environmental sensor. Transverse thrusters were fitted in addition to main propulsion systems to provide lateral thrust. DP systems first came to be used in North West European waters in the 1970s at a time of development in the offshore oil and gas industry. In the 1970s, the reliability of early DP systems gave cause for concern, there being many single point failure modes within a DP system that could result in system failure and subsequent loss of position. There were a large number of accidents and incidents at that time, leading to unacceptably high losses, including loss of life and personal injury, particularly to divers. However, since those early pioneering days considerable progress has been made and DP system technology is now accepted as a reliable and effective solution for many offshore applications.

4.1.2 Definition

Dynamic Positioning	a system which automatically controls a vessel to maintain position and heading exclusively by means of active thrust.

4.1.3 Generic Principles of DP Control Systems

All seagoing vessels are subjected to forces from wind, waves and currents as well as from forces generated by the propulsion system. The vessel's response to these forces, i.e. its changes in position, heading and speed, is measured by the position reference systems, the gyro compass and the vertical reference sensors. Wind speed and direction are measured by the wind sensors. The system calculates the deviation between the measured (actual) position of the vessel and the required position, and then calculates the forces that the thrusters must produce in order to make the deviation as small as possible. The system controls the vessel's motion in three horizontal degrees of freedom - surge (fore/aft), sway (port/stbd) and yaw (heading). Typically DP systems are used to maintain absolute position in relation to a predetermined target, e.g. a point on the seabed or on a fixed installation. However, for DP shuttle tankers the DP system is more normally required to maintain vessel position in relation to a moving target, such as the stern of an FSU/FPSO.

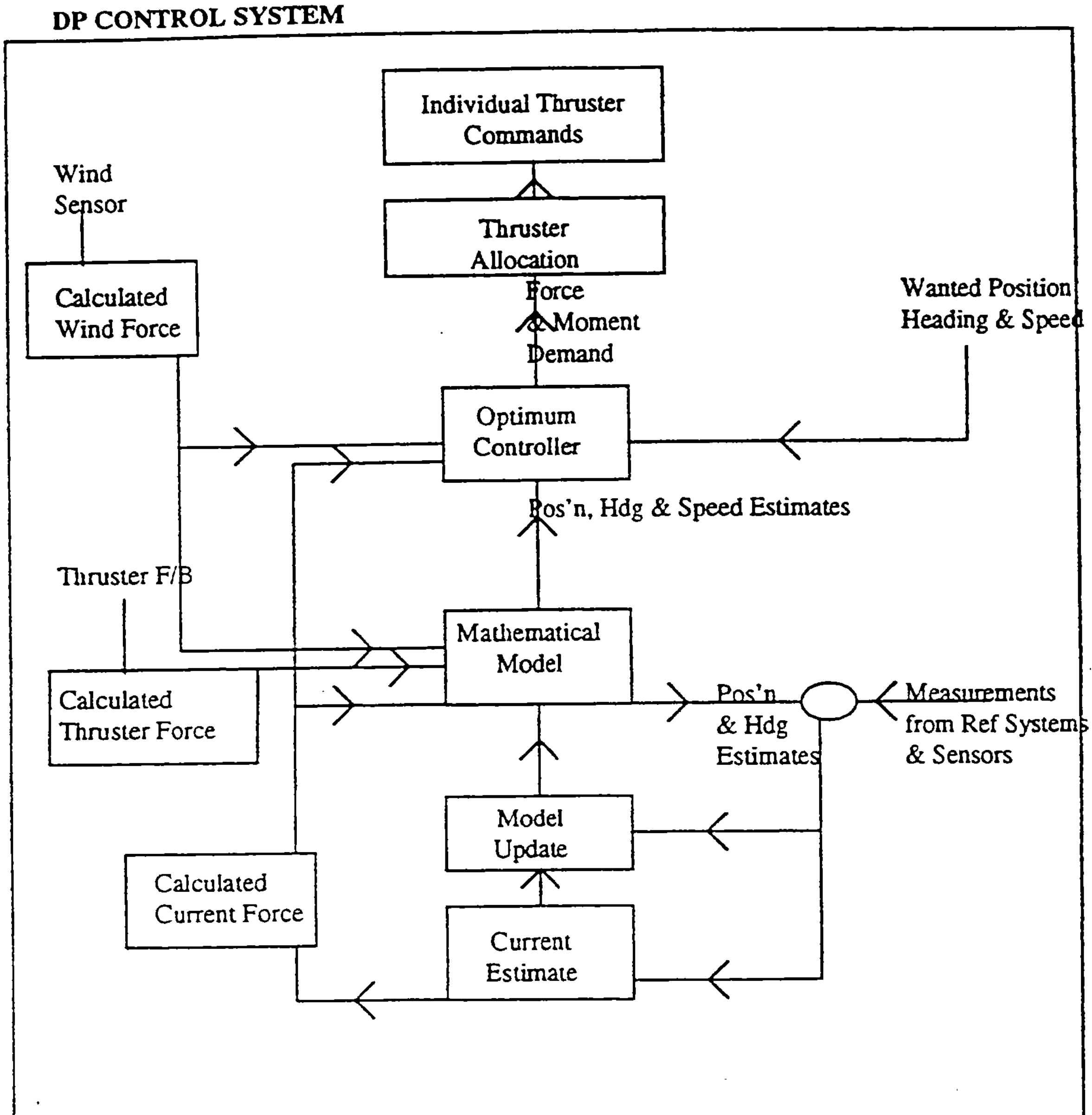


Figure 4.1 Main Elements of a DP Control System

Mathematical Model

The model is a mathematical description of how the vessel reacts or moves as a function of the forces acting on it. The model is affected by the same forces as the vessel itself. Wind forces are calculated as a function of measured speed and direction, while thruster forces are calculated as a measure of thruster output. The main output from the model is estimates of the vessel's heading, position and speed in each axis, i.e. surge, sway and yaw. The model is not totally accurate.

However, by the application of Kalman filtering techniques the model is continuously updated and this ensures that it is as accurate as possible.

Optimum Controller

The purpose of the optimum controller is to calculate the force which is to be applied by the vessel's propulsion system to maintain position. The optimum controller consists of the following elements.

Proportional Controller (P Demand)

This is proportional to the deviation between the actual and required position, such that the greater the distance away from the required position then the greater the amount of force required to recover to it.

Derivative Controller (D Demand)

This is proportional to the deviation between the actual and required speed. When a vessel is to maintain a stationary position the required speed will be zero.

Feed Forward

The controller receives input directly from the wind sensor. The effects of the wind on the vessel are known and are included in the overall calculation of required thrust allocation. The inclusion of this force directly into the calculation means that the DP system should not allow wind induced forces to move the vessel away from the required location.

Integral Action

This controller acts on the other remaining forces that are not measured and included in the calculation, such as the effects of the waves and current on the vessel. The system builds up a history of these forces over a period of time.

Thruster Allocation

The optimum controller calculates the force demand in the surge and sway axes and also the required amount of rotational movement for the yaw axis. The forces are allocated to the various propulsion units to enable the target position to be maintained.

DP System Elements

A DP system consists of three distinct elements, viz., a) power, b) control and c) references. Power can be sub-divided into power generation, distribution and consumption (propulsion). Control refers to the position control system, (DP), and to the power management system. References are sensors giving position, environmental and vessel attitude information.

MAIN ELEMENTS OF A DP SYSTEM

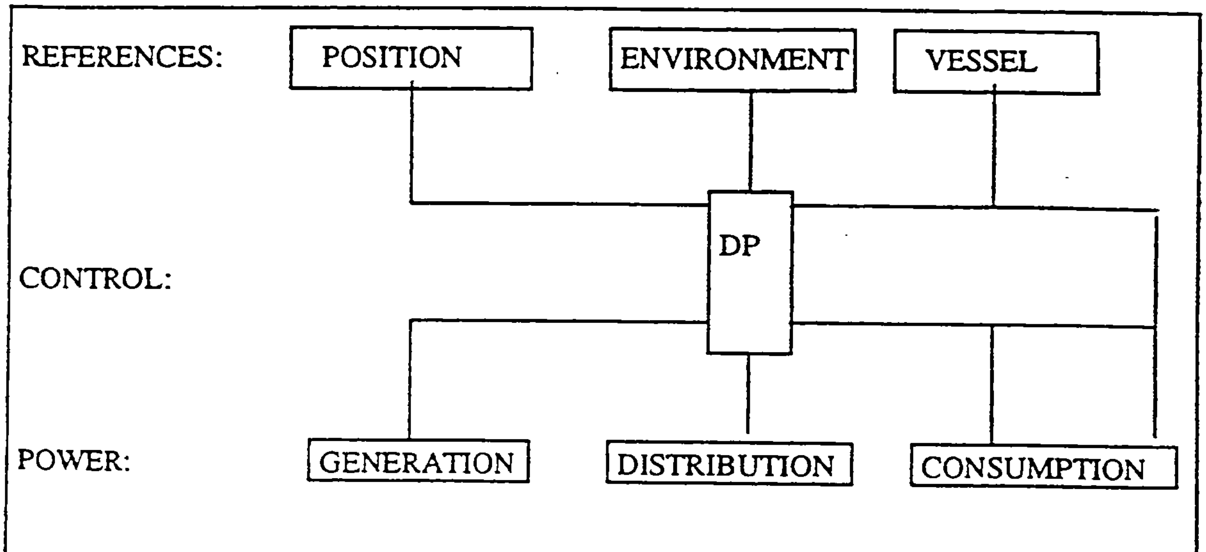


Fig 4.2 Main Elements in a DP System

The most important parts of the DP system are those which are common to several major items of equipment and, no matter how much redundancy is provided, some elements of control are inevitably common.

4.2 POWER

4.2.1 Generation

Power requirements for DP ships are generally higher than for other similar sizes of ship. The most common solution to the power requirements in most types of DP ship is to install a Diesel electric power plant. Although there are a number of DP shuttle tankers that have gone totally Diesel electric, the most common configuration is for a standard single or twin main engine driving the main propulsion plus a number of electric generating sets providing power for thrusters, etc.

In addition, there are many examples where power generating capacity is gained by installing take offs from the main engines or propeller shafts, through shaft generators, etc. Power generated in this way is often used for driving thrusters. Inevitably, where so much power is generated from a single primary source, i.e. the main engine, then the failure of that primary source can lead to a black out and total failure of the propulsion system.

One of the main differences between the operation of typical DP ships and DP shuttle tankers is that, with a few exceptions, DP shuttle tankers continue to burn heavy fuel oil in the main engines as well as in the generating sets. This was considered in Chapter 3.

4.2.2 Diesel Electric Power Generation and Distribution

In a typical Diesel electric installation a number of generators provide power to a switchboard on a 'power station' basis. The voltage required is high tension, e.g. 6kV with auxiliary systems running at 440V and 220V, power being fed from the HV switchboard via transformers. The generating sets are normally independent units with separate services, such as fuel, cooling water and lubrication. This type of configuration lends itself to the principle of redundancy, where failure of one generator still leaves a number of others on-line. Normal margins of power consumption should ensure that even after the loss of generating capacity through equipment failure there is still sufficient reserve power to maintain supply of electric power to consumers, in particular, thrusters and other propulsion units.

The principal advantage of a Diesel electric arrangement is that it can support redundant features in a way that a conventional arrangement with single or twin main engine and associated offtakes can not. A second advantage is that of space saving. Diesel generating sets take up much less room than a single main engine. Where machinery space is saved, so more cargo space becomes available. The principal disadvantage of Diesel electric systems is cost, in particular costs of installation and maintenance. As indicated in 4.2.1 few DP shuttle tankers are fully Diesel electric, but those that are will normally have greater levels of redundancy than conventionally powered tankers and should therefore be able to withstand a greater number of failure modes.

4.2.3 Power Management

Central to the concept of safe operation and redundancy in a 'power station' type arrangement is the continuous monitoring and distribution of available power to satisfy consumer demand and prevent black out. A number of operational standards apply to DP ships. These dictate the level of additional distributive power that is required to meet consumer demand in the event of a failure. The least demanding margin of additional capacity is where the power demanded should not exceed 80% of the on-line power generating capacity. More demanding requirements are where power demanded should not exceed 50% of on line capacity.

Whatever the safety margin required by the power management system the operating philosophy is the same, viz., that power generating capacity should never be less than power consumed. Power management systems can be either automated or manual, with automated systems having the edge in being able to respond more quickly to power changes than manual systems.

4.3 PROPULSION

Conventional tankers are typically equipped with single screw main propellers and have no bow or stern thrusters. As was seen in Chapter 2 DP shuttle tankers are typically equipped with more propulsion units than conventional tankers. Most DP shuttle tankers are equipped with thrusters to provide thwartships thrust. Also a small number of DP shuttle tankers have thruster type propulsion throughout. Most other DP ship types, such as DP diving ships, survey ships, cable and pipe lay ships are equipped with thruster systems as a standard.

4.3.1 Thrusters

Over the past decade thrusters have been used extensively throughout the marine and offshore industry as a means of vessel propulsion. Two main types of thruster are commonly in use, viz., tunnel thrusters and azimuthing thrusters. Tunnel thrusters are located in transverse tunnels in the hull of the vessel. Azimuthing thrusters are able to rotate 360° and may be retractable and, when in use, protrude from the underside of the vessel's hull. Typically, on DP shuttle tankers, tunnel thrusters are fitted forward and azimuth thrusters aft. Thrusters may be fixed or controllable pitch. The controllable pitch assembly, CPP, is most likely to be found. CPPs have the advantage over fixed pitch systems (FPP) that their speed of response is considerably swifter.

4.3.2 Tunnel Thrusters

Tunnel thrusters are rigidly mounted inside a tunnel which runs thwartships. They are most commonly driven by an AC constant speed motor. There are two types of drive configurations, an L-drive and a Z-drive. The L-drive has the motor situated directly above the thruster, its drive shaft being located vertically into the thruster which is in turn located on to the propeller shaft via bevel gear arrangements, hence the system is L shaped when seen from the side. A Z-drive is similar to an L-drive except that the AC motor is not situation vertically above the thruster hence a horizontal shaft is required which is connected to the vertical drive via another bevel gear, giving a Z shape arrangement. The pitch control is actuated by a horizontal piston which operates a sliding yoke mechanism. The pitch of the propeller can be moved through the entire range of positions from full port through zero to full starboard.

4.3.3 Azimuth Thrusters

Azimuth thrusters are essentially the same as tunnel thrusters with similar subsea design features, the major difference being that they have an ability to rotate through 360°. They are usually driven in the same way as tunnel thrusters with an AC motor and an L or Z-drive configuration. The thruster is normally rotated by two or more hydraulic motors. The main difference in operating conditions for an azimuth thruster compared to a tunnel thruster is its lack of circumferential rigid mounting around the propeller blades and its increased exposure to the rigours of the marine environment. Accordingly, azimuthing thrusters are more susceptible to failure than tunnel thrusters.

4.3.4 Thruster Mechanical Components

Drive Shaft

The drive shaft of a thruster runs vertically down the thruster transmitting torque from the AC motor to the propeller shaft via bevel gear. The shaft is held in place with bearings and connected to the bevel gear pinion with a crown tooth coupling. The shaft is hollow and is encased in oil.

Bearings

A thruster has several bearings which support the drive and propeller shafts. They are all of roller construction but differ in size from the small lower drive shaft bearings to the very large upper steering gear bearings. Adequate lubrication is essential to sustain bearing life. There are occasions, even when the bearing has been adequately lubricated that there is a bearing failure.

Gears

Bevel gearing is located in the lower gear box and transmits the drive from the vertical drive shaft to the horizontal propeller shaft. For maximum efficiency the step down from the drive shaft to the propeller blade speed should be within the band width of 2.8 to 4.8.

Lubricating and Hydraulic Oil

The oil system in a thruster differs considerably from normal mechanical devices as the lubricating oil and the hydraulic oil are the same, so that the oil that cools and lubricates the meshing gear teeth also controls the hydraulic components. The oil is typically contained in a pressurised holding tank well above the water line to give an over pressure of 1 bar. The oil is fed from the tank to the thruster, circulated around the unit and returned to the tank via filters.

Hydraulics

The hydraulic control mechanisms consist of the pitch control and azimuthing of the thruster. The pitch control is activated by a piston turning a sliding yoke mechanism, which in turn rotates the propeller blades. Pitch feedback is normally a mechanical linkage connected to a potentiometer. The steering capability for the azimuth thrusters is operated by two or more hydraulic motors which turn the upper steering gear. Valves are used to control the flow of oil to the various hydraulic mechanisms.

Seals

There are typically three different types of seal on a CPP thruster, viz., the blade 'O' rings, the propeller shaft seal and the upper seal or steering gear seal on an azimuth thruster. The 'O' ring seal is typically designed for 5 million pitch changes, which equates to 2 years of constant DP operations at an update rate of once every 4 seconds, or alternatively, in the region of 20,000 running hours. The propeller shaft seal is typically one of two designs, viz., either a Deepsea seal which requires the propeller shaft to be stripped for installation, whereas a Simplex seal can be installed in two parts and does not require the shaft to be stripped. Typically, the dual Simplex seal does not last as long as the Deepsea seal, but it is preferred because of its ease of installation and replacement. The Deapsea seal is normally designed for 5 year service, however it rarely lasts that length of time. The upper seal is mounted on the top of the thruster and is not susceptible to serious failures.

A number of problem areas associated with thrusters are given below.

Drive Shaft	Drive shafts and couplings do not typically require much attention, tending to be reliable components. Thorough inspection should be carried out at every opportunity to inspect for faults and cracks.
Bearings	Instances of premature bearing failure have been recorded, due mainly to the designers underestimating the requirements of thrusters in a hostile environment.

Gears	The most significant problem incurred is pitting of the surface of the gears. Additionally broken teeth and cracking can occur for a variety of reasons.
Lub. and Hydraulic Oil	Greatest problems occur when there is water ingress, followed by dirt in the oil. The water ingress problem is overcome by improved seals. Regular monitoring of the oil condition is necessary to detect early signs of problems. Typically this is carried out monthly.
Hydraulics	Sticking valves, hose breakage or disconnection, steering motor failure and failure of the pitch mechanisms have all occurred in the past, albeit infrequently.
Seal Failure	Seals are the single biggest unsolved problem of thruster design. Seal failure can lead to a number of problems, inc. water ingress, which in turn has the potential to cause bearing, gear and hydraulic failure. In general the expectations of seal designers and manufacturers are not achieved in practice.

4.4 CONTROL

The central element in the DP system configuration is the control element, consisting of computers or processors, the DP control console and the human interface. All DP systems share the same basic principles of computer application as explained at the beginning of this chapter.

4.4.1 Basics of Control Computer Operation

Generally input data is fed into the system from sensors such as position reference sensors, gyro compass, wind sensors, vertical reference sensors together with feed back from power generating plant, main propulsion and thrusters. Programme subroutines continually check the validity of the data against pre-set limits and values that are predicted from a mathematical model of the ship and the DP system configuration. The data from multiple sensors are compared and calculations are carried out to establish the accuracy of each sensor input. DP processors use the mathematical model to provide predictions on the vessel's dynamic behaviour. Measurements from the sensors are used to calculate an estimate of the vessel's position, heading and velocity. From this calculation the controller can determine the thrust allocation required to maintain or restore the set point position and heading.

4.4.2 Computer Control Tests

The processor's subroutines are initially determined at the vessel design stage. After completion the vessel should undergo DP trials during which the system can be tuned for optimum performance. Subsequent modifications to the vessel may require software updates.

4.4.3 Man/Machine Interface

The DP console provides the man/machine interface of the DP system. It is at this interface that the DP operator is able to monitor the operation of the DP system, enter commands into the DP system and intervene in the event of a failure. The DP system provides comprehensive feedback of data on one or more VDU screens, together with all control, function, display and alarm facilities. On DP shuttle tankers the DP console is located either on the navigating bridge or the bow house. The custom until recently has been to locate the DP control console in the bow house.

4.4.4 Development of Computer Control Systems

Considerable progress has been made in the provision of the control elements in DP operations. Early systems were mostly single computers and had few, if any redundant features. These were referred to as simplex systems. In the event of failure of the computer control system the DP operator had to assume control of the vessel either by joystick or manual control of the propulsion units. Further development has brought in the two computer arrangement - duplex - where failure of one computer results in automatic changeover to the standby computer. There are also DP system configurations that consist of three computers operating in a voting system, where the performance of all three computers is being constantly monitored, and where the internal performance monitoring can result in two of the computers outvoting the third. In all cases, whether using one, two or three computers, total failure of the DP control system can not be entirely ruled out, resulting in control of the vessel by the DP operator/watchkeeper.

There are various DP control systems providing the full range of computer configurations. The following table provides a list of product types that are currently in use onboard DP shuttle tankers that operate in NW European waters.

DP Computer Configuration	Manufacturer	System Name
Simplex computer system	Kongsberg Simrad Kongsberg Simrad Kongsberg Simrad	ADP 100 ADP 701 SDP 21
Duplex computer system	Kongsberg Simrad Kongsberg Simrad Cegelec	ADP 702 SDP 22 902

Table 4.1

The ADP 100 was a standard installation in the earliest DP shuttle tankers. This was followed by the ADP 700 series. Current practice is for the most modern DP systems, the SDP and the Cegelec 900 series to be fitted to DP shuttle tankers. Over the years the trend has been to provide redundancy in the provision and operation of DP control computers and typical modern configurations are equipped with two computers.

4.5 REFERENCES

The provision of accurate and reliable position reference input is of critical importance in the operation of a DP control system. There is a considerable selection of position reference systems that have a DP application. However, only a few are suitable for DP shuttle tanker operations.

4.5.1 Types of Position Reference System

The following types of position reference systems predominate in the operation of DP shuttle tankers; a) surface microwave position reference systems - Artemis, b) satellite based systems - DGPS/DARPS, c) subsea hydroacoustic position reference systems - HPR and d) fanbeam laser systems.

The most popular type of system in use on other types of DP operation is the taut wire system. However, the taut wire system is only suitable for ships that are required to remain stationed over a set point on the seabed. The set point for a DP shuttle tanker is generally related to the stern of an export FSU or FPSO or, in relation to a loading column boom. Invariably, there is also degree of weathervaning involved, meaning that the DP shuttle tanker moves in relation to the seabed.

4.5.2 Artemis

Artemis is the most commonly used position reference system in DP shuttle tanker operations. It is also the system that, generally, inspires the greatest confidence level among those who have direct operational experience of DP shuttle tanker operations. The basis of the system is a low power micro wave link which is used to send pulses to and from two transceivers.

In the standard Artemis system there is a mobile unit installed on the DP vessel and a fixed unit that is located at a fixed point in space on a fixed installation. In the standard system that is used for most types of DP ship the mobile and fixed units are very similar in that they both use tracking antennae to lock onto one another. Once locked in the mobile unit calculates the distance and the fixed unit calculates the bearing and then transmits it to the mobile station.

However, the Artemis system that is used for DP shuttle tanker operations differs from the standard configuration, in that there is no fixed point in space for the location of the fixed unit, it being located either on the stern of a FSU/FPSO or on a loading column or buoy. The fixed unit is replaced by a beacon, that consists of an omni-directional antenna. There is no calculation of bearing. The mobile unit is modified to have a bearing transmitter attached to the antenna to provide a relative bearing.

Two versions of Artemis are in current use. The Mk III is the earlier version, which has since been superseded by the Mk IV. Both versions are to be found on DP shuttle tankers. The Mk IV has some advantages over the Mk III, mainly that of being able to control the fixed station remotely from the mobile and improvements in accuracy and performance.

As far as DP shuttle tanker operations are concerned the most significant problem areas are those that are associated with distance errors. Generally Artemis distance errors are caused by the microwave link being interrupted for some reason.

A number of problem areas associated with Artemis are given below.

Excessive Vessel Motion	Caused by pitching and rolling in marginal environmental conditions. Mobile antenna moves beyond operational limits. Also, excessive roll of tanker and export facility can result in the antennae not lining up, resulting in loss of link.
Interference	Caused by a number of factors, inc. use of 3cm radar in the vicinity, SW radio, interference form other Artemis systems, self interference.
Loss of Lock	Caused by a number of factors, inc. servo motor failure, antenna damage, power supply failure.
AGC Failure	Failure of the automatic gain control circuit will result in a weak signal and can have the same effects as operating at excessive distances. This can result in a "time out" and poor performance.
Selection Mistakes	The Mk III system panel is made up of switches and controls and requires manual selection. In particular the Mk III had the option of selecting LONG or SHORT. Failure to select the correct range can result in operational problems and "time out". The Mk IV system has an automatic selection function.

4.5.3 DGPS (Differential Global Positioning System)

One of the most recent additions to the range of position reference systems suitable for shuttle tanker operations is derived from DGPS. It is known as DARPS (Differential Absolute and Relative Positioning System).

The basis of the DGPS system is GPS. GPS is dependant on 24 satellites orbiting the earth at a range of 20,000 km and transmitting radio signals to earth. The satellites act as reference points, their positions being monitored and known at all times. Measurement of the travel times from at least 3 satellites provides enough information for a global position to be calculated. The accuracy of GPS by itself is not good enough for DP, there being a number of known errors in the system, such as SA (selective address), satellite clock, orbit errors or inaccurate modelling .

A refinement has been introduced that eliminates all of these errors. A GPS receiver is located at a previously co-ordinated point, known as the reference station. It measures the raw pseudo ranges for each of the satellites in view. Comparisons between the known location of the co-ordinated point and the GPS raw position give error corrections, known as pseudo-range corrections (PRCs). These corrections, i.e. the differential corrections, can then be transmitted from the reference station to other GPS receivers on board DP vessels that are within range of the reference station. Transmission can be via ground based radio link (MF or HF) or via a satellite communication systems, e.g. Inmarsat. The GPS receivers then apply the differential correction to obtain a corrected position. Accuracy of corrected position is in the region of 1 metre.

A further refinement, DARPS, has been developed for positioning DP shuttle tankers at offshore export facilities. DARPS considers both absolute and relative components of positioning. The DGPS system described above provides information to establish absolute position and meets the requirements of most other types of DP operations. However, absolute station keeping is not suitable for DP shuttle tanker operations, where it is the relative position between the DP shuttle tanker and the export facility that is of critical importance.

In the DARPS system the absolute positions of both the DP shuttle tanker and the export facility are calculated as in normal DGPS mode. There is a radio link between the DARPS units on the installation and the tanker. The radio link is used to transmit the installation's position to the tanker. The link also transmits the installation's heading. The DARPS unit on the tanker compares the absolute position of the installation with its own position and then works out the difference. This is converted to a range and bearing of the tanker from the installation. These values are then used as a position reference input to the DP system. The DARPS system can operate in two modes, viz., a) in DGPS mode where the differential signal is transmitted to both units, and b) in GPS mode where there is no differential signal. The position errors in GPS mode are virtually nullified. Comparison of the absolute GPS positions gives a relative range and bearing of sufficient accuracy to be used as a position input to the DP system.

A number of problem areas associated with DGPS/DARPS installations are given below.

Antenna Installation	Poor installation and choice of location can result in blind spots, multi path signals and radio interference, all of which can cause satellite drop out and poor performance.
Local Disturbances	DGPS performance can be affected by the close proximity of large structures, flared gas to the atmosphere and powerful communications transmitters.
Satellite Constellation	Satellite positions are constantly changing and can give rise to changes in position performance. Susceptibility to position jumps depends on the number and geometry of the satellite constellation. There is a phenomenon known as "outliers" that can cause position jump. In addition there is a further associated problem known as "slow drift", that results in a gradual position change over a long period.
Receiver Deadlock	Receivers can occasionally "deadlock". This can be caused by the failure of one satellite's clock, thereby corrupting the positioning from the entire constellation. Internal QC packages in the system should be able to detect this type of failure.
DGPS Interfacing Standard	There are many different formats for interfacing DGPS to DP systems, inc. dedicated DGPS formats as well as "pseudo" formats, which re-configure input data to clone another position reference system, e.g. Artemis or Syledis. Different set ups can cause problems when a ship transfers between the UK and Norwegian sector of the North Sea.

Development work is currently underway that will lead to the use of the position information from Russian GLONASS satellite system. Effectively this will result in a greater satellite coverage and will help to reduce, if not eliminate, availability problems that can occur from time to time in the U.S. administered GPS system.

4.5.4 Hydroacoustic Position References (HPR)

Hydroacoustic positioning systems are used extensively as position references in DP systems, the basic principle being that it is possible to calculate with accuracy the speed and direction of acoustic pulses through water. This system uses transducers protruding from the underside hull of the ship in communication with transponders or beacons that are located on the seabed or at one or more mid-water points on a structure, such as an offloading tower. There are various configurations that are used in HPR systems. At some offshore locations there is an array of transponders located on the seabed. At others there are transponders attached to the side of the offload column or buoy.

There are a number of different operating principles that are applied in the design and operation of HPR systems. The following examples provide a basic overview of a few such systems.

The super short baseline (SSBL) system calculates a three dimensional subsea position of a transponder relative to a vessel mounted transducer. An acoustic pulse is transmitted from the onboard transducer, which interrogates the subsea transponder, which in turn replies with a pulse. The onboard transducer calculates the range and direction of the transponder and thereby calculates a position of the vessel in relation to the transponder. A number of different transponders and transducers each using different frequencies can be used simultaneously, providing flexibility and redundancy.

The long base line (LBL) system gives position information relative to a subsea array of transponders. The vessel is equipped with one or more transducers, as in the SSBL system, for the transmission of the interrogation pulse. However, the subsea array must have a minimum of three transponders to give sufficient geometry for position calculation. Also, the array must be calibrated and baselines established before the start of interrogation. In operation the ranges are measured between the vessel and the transponders and, together with the baseline data, there is sufficient information to determine the position of the vessel in relation to the transponder seabed array.

There are also combined SSBL and LBL systems that utilise a seabed transponder array, where calculations are carried out in range and in direction. Precision accuracy is achieved beyond the capability of either of the above systems operating independently.

There are a number of different configurations that may be used in DP shuttle tanker operations.

A transponder may be installed at mid-water level to an articulated loading column or to loading buoy, designed to operate on the SSBL principle. In which case, pulses from the vessel's transducer interrogate the transponder and, as a result, the relative position of the tanker in relation to the column or buoy can be calculated. Alternatively, there may be a transponder seabed array around the base of a loading column or buoy that operates on the LBL principle.

A number of problem areas associated with hydroacoustic positioning systems are given below.

Propulsion Wash	The transducer may be installed in a place where it is affected by propulsion wash. This can cause aeration at the transducer head and result in masking of the acoustic pulses, leading to loss of signal.
Blocking of Signal Path	There are various ways in which obstructions can come in between the transducer and transponder. In particular, large shoals of fish can totally obstruct or interrupt the acoustic path.

4.5.5 Fan Beam Laser

The fan beam laser is a recent introduction to suite of position reference systems that have been used for DP shuttle tanker operations. One of the most significant advantages of the system is that it is totally independent of all other systems and can be installed with relative ease. The system comprises a laser unit to measure the range, a scanner unit to scan the laser and measure the bearing of the target, a "universal display unit" that controls the system and reflective target.

The system uses the principle of laser range finding by measuring time taken for a pulse of laser light from the laser source to the target and back again, hence deducing the range of the target. The fan beam overcomes the traditional problem of narrow beam width by using special laser optics to provide a laser beam in a 20° vertical fan. By scanning the fan in a controlled manner a fixed target can be tracked from a moving vessel and its range and bearing determined.

A number of problem areas associated with the fan beam laser are given below.

Environmental Conditions	Fanbeam laser will not operate in conditions where there is sunlight shining into the lenses. Also the lenses can be affected by condensation, rain and salt spray.
Environmental Conditions	Rain, fog, snow all interrupt the line of sight and can result in loss of signal between the laser and the target.
Confusion with Reflective Materials	The laser light may latch on to reflective materials on the adjacent export facility other than the intended target , such as reflective jackets, safety notices and the hull of a TEMPSC.

4.5.6 Environmental References - Wind

One or two wind sensors, otherwise referred to as transmitting anemometers, are mounted on the DP vessel. They provide measured values of wind speed and direction, that are used as an input to the wind feed forward calculation. The siting of the wind sensors is critical, preferably in an open and exposed position, normally high up on a mast. The values from the wind sensors are used immediately in the wind feed forward calculations, therefore inaccurate measured values can have immediate effects on the quality of position control.

A number of problem areas associated with wind sensors are given below.

Upwind Obstructions	If the wind sensor is in the shadow of a part of the vessel's superstructure or a nearby installation, e.g. FPSO/FSU, then there may be air disturbance around the sensor, resulting in inaccurate values with subsequent deterioration of position control.
Helicopter Operations	Down draught from a helicopter close to the vessel's own heli-deck or on the heli-deck of the adjacent FPSO/FSU can affect the measured values and result in significant short term disturbances and deterioration of position control.

4.5.7 Vessel References - Pitch and Roll

Pitch and roll angles are required for the calculation of position. A number of position reference systems function by means of measuring angles relative to the shipboard sensor element. Therefore the pitching and rolling of the ship introduces errors into the angle calculations with result that position errors ensue. Pitch and roll angles are measured by means of one or two reference sensors, viz., vertical reference sensor (VRS) or vertical reference unit (VRU).

In general, there are relatively few problems experienced with these units. However failure and poor quality would have the following consequences.

Failure of the Unit or Inaccurate Data	Deterioration in the quality of the relevant position references and resultant deterioration in standard of position keeping

4.5.8 Vessel References - Vessel Heading

Vessel heading is invariably measured by gyro compass or gyro compasses. Heading information is required to provide a reference for control of the yaw component. Most DP ships normally operate in controlled heading mode. Typically DP shuttle tankers select weathervaning mode, where there is no requirement to control the heading. The tanker is free to adopt a heading that mininises the transverse thrust. However, there are also operational configurations that require the tanker to control heading, in which case the gyro heading input is of critical importance, such as in improved heading and position control systems.

Problem areas associated with heading monitoring are given below.

Gyro Wandering - Poor Heading Monitoring	Where there are two gyro compasses and one gyro begins to wander, difficulties are encountered in determining which of the two gyros is reading correctly. In order to overcome this problem it is recommended that three gyro compasses are installed, two of which should be interfaced to the DP system with the third being used as a reference gyro, specifically to identify which of the two interfaced gyros is reading correctly.

4.6 DP EQUIPMENT CLASS

Over the years various sets of DP consequence and equipment standards have been established by classification societies, national regulatory authorities and, latterly, the International Maritime Organisation (IMO). The purpose of establishing standards is to provide a means of measuring the reliability of DP systems. The principle at the heart of this concept is that the reliability of the DP system should be determined by the consequence of the failure of the DP system and subsequent loss of position, so that the larger the consequence the more reliable the DP system should be. The level of reliability is based on redundancy, so that the more redundant features there are, the more reliable the DP system should be.

4.6.1 Overview

For some DP operations the provision of redundancy is not required. The function of redundancy is to provide greater system reliability following component failure. This is achieved by providing more back up facilities. The requirement for the level of redundancy in the DP system should be highlighted by risk assessment and should be dependant on the consequences of a loss of vessel control.

In the UK sector the risk assessment should be carried out in accordance with the requirements of the safety case regulations. In the case of DP shuttle tanker operations the risk assessment should identify the consequences of a failure of the DP system and the potential for injury, structural and equipment damage and environmental pollution. (Generic hazards of shuttle tanker operations are considered in Chapter 5.)

Where the risk assessment considers it necessary, appropriate risk reduction measures should be put in place. One typical risk reduction measure is to reduce the likelihood of the DP failure by using tankers with high specification DP systems that incorporate a wide variety of redundant features.

4.6.2 DP Classification

Below is a summary of DP classification standards.

DPVOA (IMCA)

Levels of redundancy for a range of different types of DP vessel are given in the "Guidelines for the Design and Operation of Dynamically Positioned Vessels - 1995". These guidelines were prepared by the DPVOA and are used as a reference by designers, builders and operators. The guidelines provide specific recommendations for DP shuttle tankers as well as for DP floating production and storage systems.

IMO

Further guidance is given in an IMO document entitled "Guidelines for Vessels with Dynamic Positioning Systems". This is an internationally recognised and agreed document and applies to new vessels, constructed on or after 1st July 1994. The IMO Guidelines specify three equipment classes, Class 1, 2 & 3. Class 1 includes non redundant vessels. Class 2 vessels are those that will not suffer a loss of position as a result of a single fault or failure in any active component or system. Class 3 vessels are those that will not suffer a loss of position as a result of any single failure including all components in one fire sub-division and all components in one watertight compartment from fire or flood. The guidelines detail the level of redundancy in the various elements of the DP installation for each equipment class and outline the Flag State Verification and Acceptance Document (FSVAD) which states the equipment class for the vessel.

Classification Societies

Classification societies have issued class notations for DP vessels that are based on the levels of redundancy and are consistent with the IMO guidelines. Relevant notations are given in the table below. Only three classification societies have been considered in this report, viz., DNV, Lloyds and ABS, all of whom have considerable experience in the classification of DP vessels. NMD Classification has also been included for the purposes of comparison.

DP CLASSIFICATION EQUIVALENCE TABLE - CLASS NOTATIONS

IMO Class	DNV	NMD	Lloyds	ABS
Class 0	Dynpos Auts	NMD Class 0	DP (CM)	DPS-0
Class 1	Dynpos Aut	NMD Class 1	DP (AM)	DPS-1
Class 2	Dynpos Autr	NMD Class 2	DP (AA)	DPS-2
Class 3	Dynpos Autro	NMD Class 3	DP (AAA)	DPS-3

Table 4.2

NMD

The Norwegian authorities have gone one stage further than establishing standards for equipment classification. The applicable publication is known as "Guidelines and Notes for Mobile Units" and is issued by the Norwegian Maritime Directorate (NMD). These guidelines apply to the operation of DP ships in Norwegian waters and cross reference equipment class requirements against potential consequence, thus going further than the IMO guidelines and classification society rules, that are based on equipment standards only.

CONSEQUENCE APPLICATIONS OF NMD GUIDELINES

Equipment Class	Application
Class 1	Operations where loss of position is not considered to endanger human lives, cause significant damage or cause more than a minimal pollution.
Class 2	Operations where loss of position could cause personnel injury, pollution or damage with great economic consequences.
Class 3	Operation where loss of position could cause fatal accidents, severe pollution or damage with major economic consequences.

Table 4.3

4.6.3 Applicability of DP Equipment Classification to DP Shuttle Tankers - Discussion

Most types of DP operation require a specific DP equipment standard. For example, DP diving and DP drilling operations and DP accommodation unit operations are generally required to operate to equipment class 2 or 3. The actual standard depends to a large extent on the regulatory regime and/or the accepted practice in the sector. In Norway, for instance, equipment class 3 is required by the regulatory regime for all of the above, whereas in the UK the offshore operator is given greater freedom to choose the level of equipment class. As indicated in 4.6.1 in the UK the standard of equipment class required for a particular operation should be directly related to the risks identified for that operation.

It is normal for DP ships to be given an appropriate class notation that indicates the DP equipment standard of the ship. This covers the full range of DP ships, including diving ships, drilling units, accommodation units, cable and pipe layers, survey ships and also supply vessels. The classification process ensures that external independent supervision is exercised in DP system design, verification and continued fitness for purpose, including testing and trials.

Apart from a few exceptions, especially new buildings, DP shuttle tankers are not normally given DP equipment class notation in the same way as other types of DP ship. Each tanker has to be considered on its own merits. It is a fact that most DP shuttle tankers do not easily fit into appropriate classification categories, many having a mix of class categories. For example a tanker may be equipped with a duplex computer control system (class 2) yet have only one main engine and single main propulsion and may also have a number of power offtakes from the main propeller shaft to power the transverse thrusters (class 1).

On the operational side there appears to be no consistency in the utilisation of DP shuttle tankers of the same class at the various types of export facilities. For example, as indicated in Chapters 2 & 5, there are marked differences in the risk ratings associated with different export facilities. OTBE the risks associated with offtake operations at FSU/FPSOs are generally considered to be greater than at SPMs and significantly greater than at sub-sea offtakes such as OLS and STL systems.

There appears to be a difference in utilisation philosophies of DP shuttle tankers between Norwegian and UK sectors. A trend is appearing in Norway, although not as part of a regulatory requirement, where the export facilities with the highest category of risk are served by tankers with the greatest levels of redundancy, nominally class 2 equivalent. However, to a large extent in practice in large tracts of the UK sector, class 1 and class 2 equivalent DP shuttle tankers appear to be totally interchangeable, so that both types are utilised at the export facilities with the highest risk rating.

4.7 DP OPERATOR COMPETENCY

Training and competency issues have been recognised as key elements in the management of DP operations for many years. The importance of this human dimension is seen in the results of the DP incident analyses carried out by the DPVOA (IMCA). For example, the results from 1993 indicate that 25% of all DP incidents were caused principally by operator error. The comparable statistic for 1995 is 15%.

The DPVOA have been at the forefront in establishing training and experience requirements for DP operators. A set of guidelines, "The Training and Experience of Key DP Personnel", was published and issued to IMO in 1996. These guidelines provide a standard for the DP sector as a whole and apply internationally. However, the guidelines are mainly framed within the context of meeting the requirements of other DP ship types, such as diving, drilling, accommodation units, pipe layers, cable layers, survey ships etc., and are not entirely appropriate to DP shuttle tankers. This section provides an overview of issues related to DP operator competency and discusses some specific examples. There is also a brief discussion of current DP watchkeeping practices on DP shuttle tankers and their implications for the safety of the DP operation. These issues are key elements in DP shuttle tanker capability.

4.7.1 Human Resource Competence Assurance

Successful dynamic positioning is a product of a combination of essential elements, a major one being the human perspective. Integrated teamwork combined with personal competency in all aspects of DP operations contribute to the optimum utilisation of human resources. This is true of all ship types, including DP shuttle tankers as well as DP diving vessels. A common factor linking the two ship types together is that, in relying on DP for maintaining vessel position, it is possible that a position loss arising out of a failure of the DP system could have serious implications, potentially leading to significant loss, including personal injury, structural damage, environmental pollution, etc. In establishing risk reduction measures it is important that the quality of the DP system and its elements is linked to the level of risk and potential worst case consequences, so that as the level of risk is increased so the quality of DP system and its elements is also increased. This includes the human resource element.

OTBE, a DP shuttle tanker operating at an FSU/FPSO export facility is exposed to greater risk than at other types of export facility, such as an SPM or an OLS. As a result, in so far as DP shuttle tankers are concerned, maximum effort should be exercised in achieving competency in all relevant aspects of DP across a wide range of personnel, including those that have responsibilities for operating the DP control system as well as those whose role lies in the provision and maintenance of essential services and equipment. Typically this means that appropriate competence assurance processes should be in place for the following key positions on board all DP ship types; master, DP operators (watchkeeping officers), engineers, electronics and electricians.

The only way of achieving human resource competency is to provide appropriate training and education. The internationally recognised standard for DP training and competency is contained in the IMCA document, "Training and Experience of Key DP Personnel".

4.7.2 Overview of IMO Approved DP Training Standards

The principal international standard dealing with competency issues for watchkeepers at sea is the IMO STCW Convention 1995. The Convention is seen as the way ahead to improve overall standards of watchkeeping, including navigational and engineering. The Convention is based largely on applying vocational qualification (VQ) techniques to establish competency. However, competency issues for DP watchkeepers are excluded from the Convention. IMO has not ignored the issue of DP competency, its Maritime Safety Committee (MSC) having referenced the IMCA training document as an industry standard. As a result the document has gained an authoritative position in the DP sector and the standards set out in the document should be applied to all DP training and competency schemes.

The following paragraphs provide an overview of principal elements of the training document.

Objectives

The primary objectives are to define minimum standards for;

- the provision of formal training of key DP personnel
- maintaining continuity of vessel experienced personnel on board a DP vessel
- the familiarisation programme for key DP personnel new to a vessel

The achievement of the primary objectives should assist in achieving the following secondary objectives;

- acceptance of an internationally accepted standard for training
- optimisation of training resources
- provision of on board training and familiarisation programmes and simulators

Types of Training

It is recognised that competency in DP is achieved by using a combination of different techniques, including the following;

- formal shore based training
- onboard training under the supervision of an experienced operator
- on board DP simulator instruction and exercises
- ship specific onboard instruction and familiarisation
- supervised operation of the control system
- manufacturers' training courses ashore and on board
- seminars and open discussion on vessel operations
- equivalent approved company schemes

DP Training Courses

The training document gives a structure of approved DP training courses for various positions, including DPOs, ETO/EROs (electricians/electronic officers) and engineers. Approvals for training courses are given through a DP validation scheme that is administered by the Nautical Institute (NI). In addition the Norwegian Maritime Directorate (NMD) issues approvals.

The following are given as an examples of standards required to achieve competency as a DPO. In the context of the competency of DP shuttle tanker personnel the person on watch with operational responsibility for the control of the DP system should have gone through the training programme below.

Phase 1 — Attendance at a DP induction course at an approved institution or organised on board, where the course will provide an introduction to the functions and use of a DP system, or as a trainee DPO with on board training under the supervision of an experienced DP operator. The course should be based on contents of the training document.

Phase 2 — Documented practical experience in the use of DP systems on DP vessels for a minimum period of 30 days as a trainee DPO.

Phase 3 — Attendance at a DP simulator course at an approved training institution or on board the vessel, where the course will provide training in the use of the DP systems, including simulator exercises and emergency operations. The course should be based on the contents of the training document.

Phase 4 Documented confirmation of 6 months supervised DP watchkeeping in an approved DP Log Book from the master/OIM and that the above training programme has been followed and completed will result in the issue of a DP certificate.

Training courses are also required for ETO/EROs who should attend DP control system manufacturers maintenance courses to enable understanding of the control system as well as fault finding procedures. The courses should be held at an approved institution or organised on board the vessel. Similarly special training courses are also recommended for chief engineers and other watchkeeping engineers. Appropriate courses are on DP control system maintenance. In any event engineers and electricians should have a full understanding of the risks involved in DP operations and of the consequences of maloperation or failure of the DP system and should also fully understand their role in the successful DP operation of the vessel

Suitability of IMO Approved DP Training Standards to DP Shuttle Tanker Sector

There are a number of specific reasons why the above standards are not wholly suited to the DP shuttle tanker sector. Principally, the length of time required to achieve phase 4 level of training is in excess of 7 months, excluding time for two courses. There is no definitive interpretation of qualifying time, it being generally understood that qualifying time is time spent onboard the vessel when it is engaged in DP operations. As indicated earlier in this report typical DP shuttle tankers spend considerably less time in DP than other DP ship types and, as a result, it would take considerably longer for watchkeepers on DP shuttle tankers to attain phase 4 level training.

4.7.3 Standard Industry Practice

During the course of the project a number of examples of DP training and competency programmes were considered and it is evident that there are various standards across the DP shuttle tanker sector. It also appears that considerable efforts are being made to achieve compliance with the IMO approved standard.

The following table provides an overview of four typical training and competency programmes for DPOs.

	DP Induction Course (Phase 1)	DP Simulator Course (Phase 3)	Ship Manoeuvring Course (Non-DP)	Personnel or Bridge Resource Management Course
Example 1	✔	✔	✔	✔
Example 2	✔	✔	✔	✕
Example 3	✔	✔	✕	✕
Example 4	✔	✔	✔	✕

Table 4.4

On the evidence of the tabulated information above, compliance is achieved in all examples and exceeded in all but one. However, from the point of view of practical implementation, compliance is not universal, there being a number of cases where fact falls somewhat short of the target, particularly in relation to qualifying time and the omission of the DP simulator course. There is also provision for refresher courses in the above examples. The concept of refresher courses is not fully developed and as yet there is not a clear pattern that can be reasonably represented in the above table.

The ship manoeuvring course above is designed to give participants practice in handling tankers and covers basic and advanced levels. Ship manoeuvring courses require full bridge simulator facilities.

Personnel and bridge resource management courses provide training in achieving the most effective utilisation of human resources from an individual as well as from a team work perspective in both normal and emergency situations.

Competency Assurance

The training courses do not generally feature competency assessment. Attempts have been made at one training centre to introduce competency assessments, yet have been terminated. Competence assurance is built around the twin pillars of training programmes as above and operational experience, there being no formalised assessment system such as that which applies to airline pilots.

4.7.4 Watchkeeping Practices

As indicated previously in this report there are differences in watchkeeping practices between DP shuttle tankers and other DP ship types. The typical arrangement onboard DP shuttle tankers is for the master to remain in active control of the DP console for the entire duration of the offtake operation. Simultaneously the chief officer also remains active for the same period, his responsibilities being to supervise the cargo operation. Depending on the nature of the operation this period is typically between 18 and 36 hours, during which neither the master nor the chief officer is liable to get adequate rest. Where offtakes take place every four to five days, not an abnormal frequency, this means that sleep patterns can be disturbed, with resultant problems of fatigue, stress and other fatigue related conditions. These practices are generally regarded in the sector as being unavoidable features of DP shuttle tanker operations.

Cultural Gap

However, such practices also provide demonstrable evidence of the existence of a cultural gap between the offshore sector and the tanker sector. The offshore sector generally has adopted a more structured system that is capable of continuous operation over a 24 hour period day in day out. In the offshore sector continuity of function is more important than continuity of personnel. This means that there are two persons for most positions on an offshore installation. As a result offshore manpower requirements are based on this principle. However, this is not generally the case on DP shuttle tankers, where traditional tanker manning principles apply, i.e. master, chief officer plus two other navigating/deck officers.

Offshore Industry Hours of Work

Hours of work arrangements on offshore installations are generally equal periods of duty and rest, typically 12 hours on followed by 12 hours off. This ensures adequate periods of rest. In addition the general practice in other offshore related marine activities is to organise duty periods to provide adequate rest periods. For example, this is seen in the watchkeeping practices on such vessel types as DP diving ships, cable layers, crane barges and offshore supply ships. Typical arrangements on other DP ship types are for a two man DP watch, changing out every 12 hours. Also the standard practice on offshore supply ships is for the master to delegate ship handling control of the vessel regularly to the mate. This delegation of operational responsibility allows continuous operation to be carried out without the problem of the onset of fatigue.

Regulation and Guidance

There are various regulations and guidance notes influencing hours of work at offshore installations. There is Norwegian regulation as well as guidance from the UK's HSE setting out acceptable hours of work. As far back as 1990 the UK's Petroleum Energy Division issued safety notice PED5 1/90 that recommended a 12 hour day should be considered as normal, also recommending that only in very exceptional circumstances should the period of duty exceed 16 hours.

Not only is there an hours or work standard for offshore installations in Norway and in the UK, there is now a minimum standard that applies to all ships world-wide. This standard is included in the recently published STCW Code and sets hours of work and rest criteria for all watchkeeping personnel, stating, among other things, that a minimum of 10 hours rest should be provided in any 24 hour period. On the basis of the information gathered during this project there is little evidence of compliance with these standards.

5. HAZARD ASSESSMENT

So far this report has considered the many and varied factors that influence the conduct of offshore offtake operations. The principle on which this approach is based is that the most thorough way of finding solutions to individual problem areas is to consider, in a holistic way, the total circumstances in which offshore offtake operations take place. Thus, for example, the route to resolving specific problems associated with close proximity and separation distances between the shuttle tanker and the export facility are not to be found solely in an examination of the immediate influencing factors but should be examined against the background of all circumstantial factors, including, the organisation of the industry, the capability and reliability of the shuttle tankers, the types and characteristics of offtake facilities and the human perspective. The preceding chapters have dealt with such circumstantial factors. However, this chapter deals in greater depth with the operational and technical factors that have an immediate impact on one particular problem, that of close proximity, including an assessment of separation distance.

5.1 APPROACH TO HAZARD ASSESSMENT

5.1.1 Background

Clearly, to use large shuttle tankers, some of 150,000 tonnes deadweight capacity and to operate them in close proximity to similar sized FSU/FPSOs at offshore production locations in harsh environmental conditions does present a palpable risk of collision. Notwithstanding the various collision risks that are present in any marine logistics environment it is, in particular, the risk of collision between the shuttle tanker and the FSU/FPSO that is the major concern of the industry and it is that which is dealt with here. One of the major influencing factors in any close proximity situation is separation distance. OTBE the shorter the separation distance the greater the risk of collision. During the course of this project it was established that nominal separation distances differ across the offtake sector. The following table gives an overview of the factors that influence the separation distance, including hawser length. The information contained in the table was gathered in the series of meetings held during the project. The information is representative of a small sample only and is not to be considered as providing a comprehensive overview.

NB. In order to keep the hawser slack when in DP the nominal separation distance will normally be in the region of 10 metres less than the hawser length. Where tankers are non-DP then the hawser remains under tension and hawser length is the nominal separation distance.

Export Facility	Location	Sector	DP/non-DP	Hawser Length	Hose Length
FSU 1	Central North Sea	UK	DP	80m	110m
FPSO 1	Central North Sea	UK	DP	85m	115m
FPSO 2	Central North Sea	UK	DP	80m	120m
FPSO 3	Central North Sea	UK	DP/non-DP	47m	-
FPSO 4	Atlantic Frontier	UK	DP	120m	-
SPM (ALC)	Central North Sea	UK	DP/non-DP	77m	65m
FSU/FPSO	Northern North Sea	Norway *	DP	80m	-
SBM	Northern North Sea	Norway *	DP	60m	-

Table 5.1

* The values in this table for Norwegian waters represent the accepted standard for that sector.

As can be seen from the table hawser lengths vary in the UK sector, although it appears that the standard length is 80m, as in Norway, there are examples where the distance is shorter, the shortest being 47m, and others where the distance is longer, the longest being 120m in the Atlantic Frontier. There are other differences, viz., in the type of facility and in type of shuttle tanker. In the case of FPSO 3 offtakes can be carried out by DP or non-DP shuttle tankers. Where a non-DP shuttle tanker is used, the tanker keeps a tension of 20 to 30 tonnes on the hawser by maintaining an astern movement.

5.1.2 Hazards of Dynamic Interaction

It is in the area of dynamic interaction between the shuttle tanker and the FSU/FPSO where the most critical problems arise. As indicated in Chapter 3 of this report there are two specific dynamic interactions that give particular cause for concern, viz., fishtailing and surging. The extent of the problem is wide enough for all of the participants in the project to be aware of it and to acknowledge first hand experience of it.

The shuttle tanker sector has been aware of the problems for many years and efforts have been made on a number of fronts to deal with the problem. In the first place there are procedural methods available designed to prevent the problems from occurring. There are also procedural methods available to deal with the problems after they have arisen. In addition DP system manufacturers are currently involved in the development of position control software and systems that are designed to overcome the problems associated with fishtailing and surging and will enable the DP shuttle tanker to maintain more accurate and reliable position keeping in close proximity to the FSU/FPSO.

This chapter provides a description of both problems and outlines the risk reduction methods.

5.2 FISHTAILING

5.2.1 Description

Currently, the typical control mode for DP shuttle tankers at all offtake facilities, including FSU/FPSOs is to weathervane. The weathervaning heading strategy utilises the stabilising effect of the wind and wave forces on the tanker's hull. In this mode the DP control system seeks to find the tanker heading that offers the minimum sideways force, i.e. minimum sway characteristics, the heading being a function of the transverse forces. The tanker's propulsion is then used to maintain the separation distance between the tanker and the FSU/FPSO.

Typically the preferred close proximity tanker-FSU/FPSO alignment is for the bow of the shuttle tanker to point directly towards the stern of the FSU/FPSO, see fig 5.1. Where the FSU/FPSO has no heading control or DP control itself then the FSU/FPSO is generally free to rotate about its point of rotation and adopt a heading that is in line with the main environmental forces acting on it. Where the FSU/FPSO is in loaded condition with a substantial draft then it is normal for the surface current force to be dominant and for the FSU/FPSO to be predominantly current rode. However, where the shuttle tanker is in ballast condition with reasonably shallow draft then typically the tanker will be more responsive to wind forces than to surface current forces and is more likely to be predominantly wind rode.

Examples of fishtailing are illustrated in the figures 5.2, 5.3 and 5.4 below.

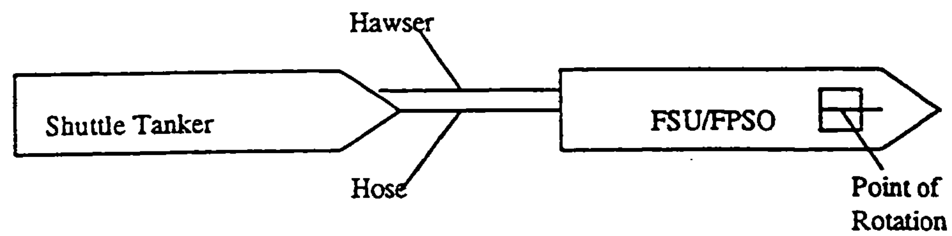


Fig 5.1 Tanker - FSU/FPSO in Alignment - No fishtailing

Fishtailing generally occurs when the environmental forces are reasonably low in magnitude. It is also principally a phenomenon that occurs when there is considerable dissimilarity in hydrodynamic characteristics between the tanker and FSU/FPSO. As a result the variable factors that contribute towards fishtailing are continuously changing. During the course of the offtake operation the FSU/FPSO becomes lighter and is subject to influence by a different combination of hydrodynamic forces, becoming more under the influence of wind than wave or current. Similarly, the shuttle tanker's condition changes, becoming heavier, tending to be more under the influence of wave and current than wind.

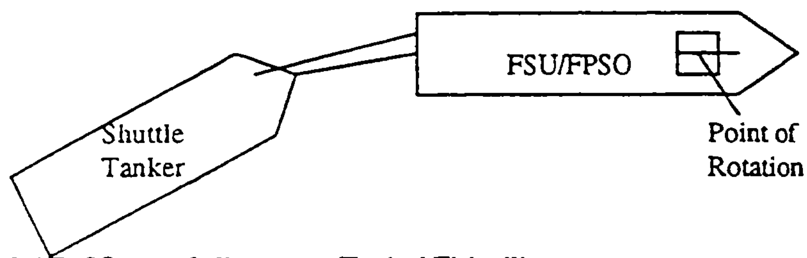


Fig 5.2 Tanker - FSU/FPSO out of alignment - Typical Fishtailing

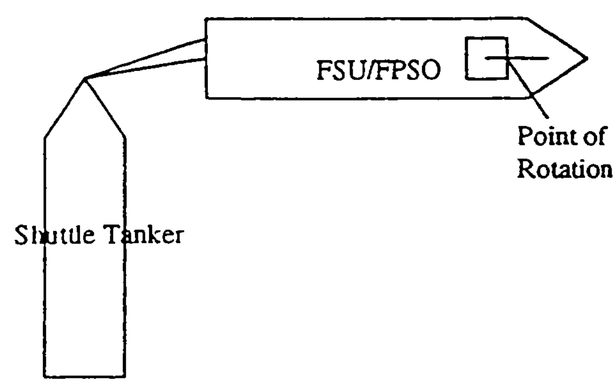


Fig 5.3 Tanker - FSU/FPSO Out of Alignment - Extreme Fishtailing

Additional complications arise when the environmental forces change in direction during the course of an offtake. As far as the surface current is concerned, this generally occurs in accordance with the tidal cycle. However, wind is not so predictable. Where the FSU/FPSO is free to rotate about its point of rotation in a set of changing environmental forces then its heading will change. If the tanker is to remain in alignment with the FSU/FPSO then the arc of the circle of rotation that the tanker must describe is considerably greater than the arc described by the FSU/FPSO. Where the changing combination of environmental forces are free to influence the tanker and FSU/FPSO then the outcome can be as extreme as the example in fig. 5.4 below. In reality once it is determined that the environmental forces are subject to significant change then an appropriate manoeuvring action should be taken on the tanker to enable it to remain in alignment as in fig. 5.1 above. Such action could be to use a combination of heading changes and transverse thrust to keep it in line with the FSU/FPSO. Alternatively, an astern movement could be used to maintain some tension on the hawser. This has the effect of turning the tanker and FSU/FPSO into one unit, so that there is more likelihood of the combined environmental forces exerting the same influence on both tanker and FSU/FPSO.

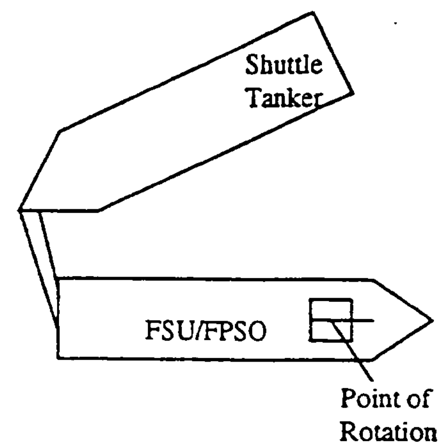


Fig 5.4 Tanker - FSU/FPSO out of Alignment - Most Extreme Fishtailing

5.2.2 Problems Associated with Fishtailing

A number of operational and safety related problems are liable to be experienced during fishtailing.

Operational and Safety Related Problems

- Possibility of the hawser and hose becoming crossed, resulting in abrasion and possible damage to hose and hawser.
- Possibility of obstructions in way of the Artemis line of sight between the tanker and the FSU/FPSO, resulting in loss of position reference signals.
- Less room for manoeuvre when at extreme angles in the event of emergency, especially when in the position illustrated in 5.4.
- Reduction in separation distance at the bow and along the length of both tanker and FSU/FPSO, resulting in increased exposure to risk of collision.

5.2.3 Risk Reduction Measures

A number of risk reduction measures are applied to prevent fishtailing, some of which have been referred to in 5.2.1 above. They include the following.

Risk Reduction Measures

- On the tanker, monitor the heading of the FSU/FPSO and as its heading changes so make minor adjustments to the heading of the tanker and use transverse thrusters to keep the tanker and the FSU/FPSO in alignment.
- On the tanker, where there is no DP control or where transverse propulsion is inadequate, use the support vessel under tow to pull the stern of the tanker in the appropriate direction, thus achieving alignment.
- On the tanker, when it is detected that fishtailing is set to be a problem, apply astern thrust to the main propulsion to exert small amount of tension on the hawser, thus making the tanker and FSU/FPSO combination one cohesive unit as far as the environmental forces are concerned.
- Apply heading control to the FSU/FPSO so that the FSU/FPSO is not free to rotate in accordance with external environmental forces.
- Where heading control and/or heading monitoring is available on the FSU/FPSO, transmit the FSU/FPSO heading directly to the tanker and use as an input to the DP control system. This means that the tanker is no longer able to operate in accordance with the principles of weathervaning. This requires the DP system to provide control in all three axes, surge, sway and yaw. This principle is applied at various offtake facilities with considerable success. See 5.4 for a description of recent DP control developments.

5.3 SURGING

5.3.1 Description

This is a well known problem during offtake operations, particularly at FSU/FPSO facilities. The shuttle tanker may experience long period waves in excess of 15 seconds frequency with the result that the tanker begins to surf on the crests. This can lead to large alongships oscillations if the fore and aft propulsion is unable to dampen the motions adequately. While the tanker is subjected to such surface influenced fore and aft movement the FSU/FPSO, being secured to the seabed, generally by a chain and wire mooring arrangement, is subjected to different hydrodynamic forces and at different levels. In part much of the fore and aft motion experienced by the FSU/FPSO is dampened by the mooring system. As a result of the differences of the environmental forces the fore and aft motion of the FSU/FPSO may be significantly different from the fore and aft motions of the shuttle tanker, resulting in asynchronous movement. The worst case scenario is where the FSU/FPSO moves astern at the same time as the shuttle tanker moves ahead, thus reducing the separation distance. The movement of the shuttle tanker is not only influenced by the environmental forces. There is also propulsion induced movement caused by DP control system signals acting on the position reference information, so that the DP system acts on changes of the separation distance between the tanker and the FSU/FPSO. The aim of the DP system is to maintain a stable separation distance. A possible solution to this problem based on a modification of traditional DP control system logic is considered in greater detail in 5.4. The following figures illustrate the basic problem of surging and some of the complications.

The following sequence of figures serves to illustrate in the most basic way some of the effects of dynamic interaction on the tanker and FSU/FPSO combination caused by long swell.

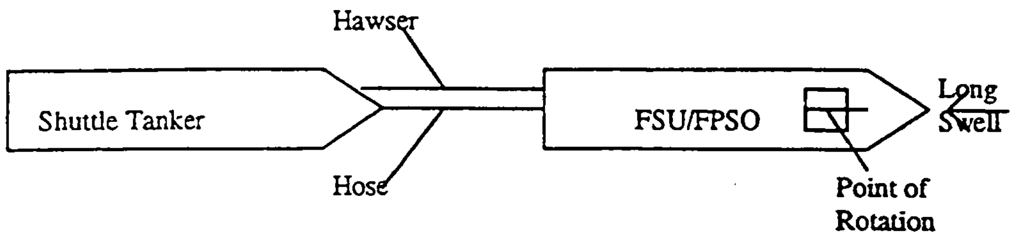


Fig 5.5 Tanker - FSU/FPSO in Alignment

In the figure above there is a long swell but there is no relative movement between the tanker and the FSU/FPSO. Assume that the separation distance is steady at 70 metres. The hawser is slack.

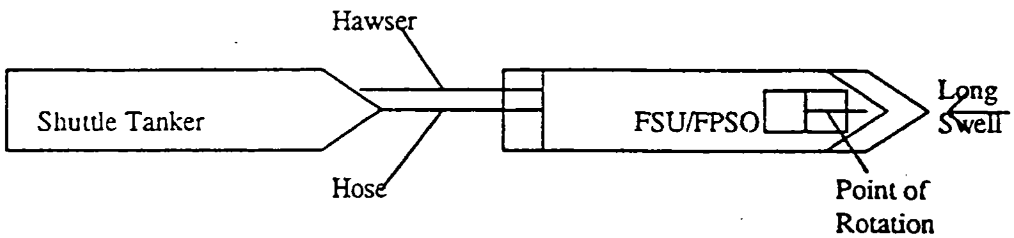


Fig 5.6 Tanker steady - FSU/FPSO moves astern caused by long swell - separation distance decreases

In the figure above the FSU/FPSO begins to move astern. The movement is caused by the combined effects of the long swell on the subsea mooring system and on the hull form of the FSU/FPSO. The tanker remains steady. The astern movement of the FSU/FPSO has reduced the separation distance to 60 metres.

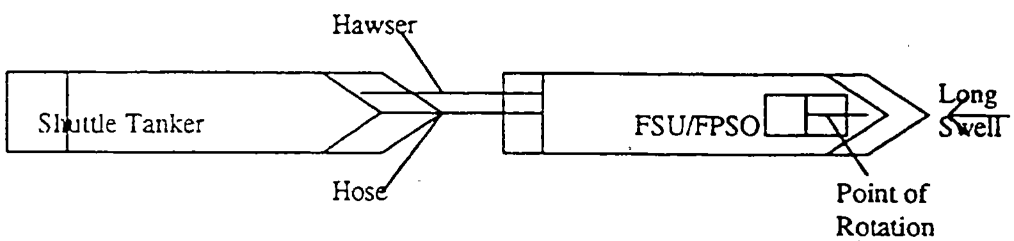


Fig 5.7 Tanker moves ahead caused by long swell - FSU/FPSO still astern of target location - separation distance decreases further

In the figure above the FSU/FPSO remains steady in position offset some 10 metres astern of its target position. In the meantime the swell has acted on the more responsive shuttle tanker which surges ahead some 20 metres, thus reducing the separation distance to 40 metres.

The combination of movements and the figures used in the examples above are purely indicative and are intended to illustrate in the simplest form possible the potential consequences of dissimilar movements, viz., that of reducing the separation distance.

The following sequence of figures illustrates a complication in the dynamic interaction that is caused by the hawser connection in the DP shuttle tanker - FSU/FPSO interface.

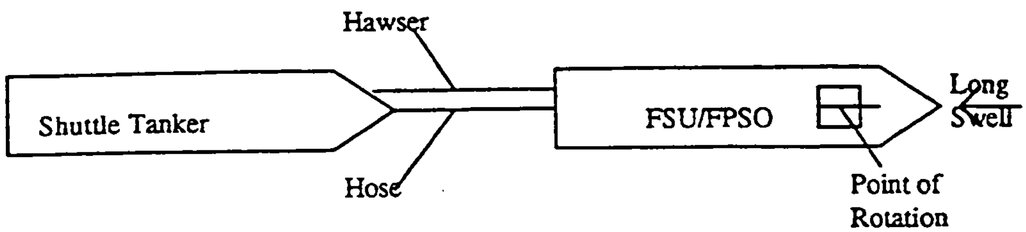


Fig 5.8 Tanker - FSU/FPSO in Alignment

In the figure above there is no relative movement at the DP shuttle tanker - FSU/FPSO interface. The separation distance is steady at 70 metres. There is 10 metres slack in the hawser.

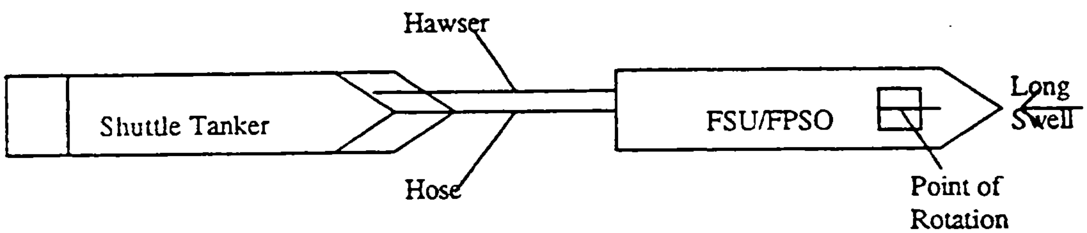


Fig 5.9 Tanker - FSU/FPSO in Alignment. Tanker moves astern on swell.

In the figure above the DP shuttle tanker begins to move astern on the long swell. The FSU/FPSO remains stationary over its target location. The tanker's astern movement is considerable and given no restrictions the tanker would move a total of 20 metres astern. However, the hawser prevents the completion of this wave induced stern movement. The tanker comes to a stop at approximately 80 metres from the stern of the FSU/FPSO. The hawser goes tight and its recoil action propels the tanker in a forward direction. The effects are seen in the figure below.

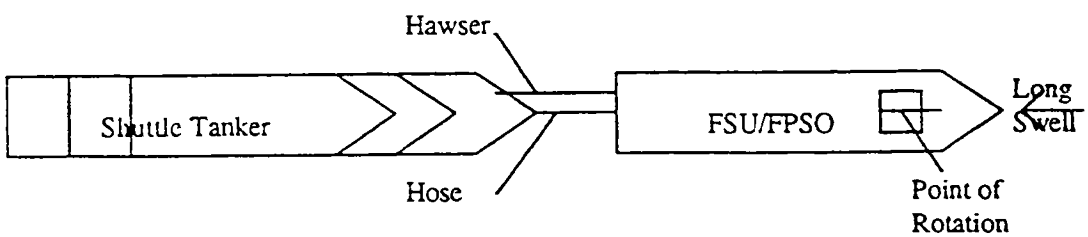


Fig 5.10 Tanker - FSU/FPSO in Alignment. Tanker moves ahead on release of stored energy in hawser

In the figure above the release of the stored energy in the hawser has propelled the tanker forward and beyond its original separation distance of 70 metres and as indicated in the figure the final distance may be down to 30 metres. Without any restrictions on the movement of the tanker it would continue its forward momentum and collide with the FSU/FPSO. Clearly the relative motions illustrated above are indicative only. They are based on a number of assumptions. For example it is assumed that the FSU/FPSO is stationary. It is also based on the premise that the tanker has no propulsive capacity to apply some counter directional thrust away from the FSU/FPSO.

5.3.2 Problems Associated with Surging

A number of operational and safety related problems are liable to be experienced during surging. The extent of the problems of movement may be even greater than shown in the figures on the preceding pages. The overall view across the DP shuttle tanker sector is that surging is the most critical hazard affecting offshore cargo offtakes. It is a problem that is associated particularly with long swells, typically in excess of 15 seconds frequency. Although such swell periods may not be altogether common in North Sea areas, the Atlantic Frontier is frequently subject to such environmental conditions. Therefore the problem is likely to be more prominent in that geographical area. Refer to the table in 5.1.1 where the hawser length for the Atlantic Frontier export facility is 120 metres. The decision to choose such a long hawser length was based on the objective of increasing the nominal separation distance so as to allow for greater freedom of movement of the tanker in long swells. The problem is also likely to be associated with periods of adverse weather.

Operational and Safety Related Problems

- Dissimilar fore and aft movements result in rapid changes to separation distance between the tanker and the FSU/FPSO, in turn resulting in rapid engine movement changes from ahead to astern. In the case of some DP shuttle tankers during the entire cargo offtake there is a constant ahead/astern movements.
- Failure modes that cause instability in the propulsion movements, e.g. failing to full ahead or astern, can have serious consequences and result in collision.

Risk Reduction Measures

A number of risk reduction measures are used to combat the problem of surging.

- By reducing the nominal separation distance between the tanker and the FSU/FPSO there is less likelihood of the tension appearing in the hawser when the tanker moves astern on the swell. This practice is exercised by a number of tanker masters, the nominal separation distance being, in some instances, reduced to 30 metres.
- Come out of DP control and maintain small amount of tension on the hawser.
- Appropriate DP control software is under development. The software takes account of the absolute and relative positioning between the tanker and the FSU/FPSO. See 5.4 for a description.

NB This report does not express a judgement on the correctness or otherwise of the above measures

5.4 IMPROVED DP CONTROL SOFTWARE

The dynamic positioning logic has to take account of the fact that neither the FSU/FPSO nor the shuttle tanker is fixed in position. If the position of the FSU/FPSO was stationary then the positioning could be absolute, i.e. the tanker could set a target location at a fixed point in space. This is impossible to achieve in a FSU/FPSO - shuttle tanker interface. In a purely relative system the tanker sets a target location that relates to a specific point on the FSU/FPSO that is not fixed in space. This is the conventional arrangement for the FSU/FPSO - tanker interface. This mode is not without the problems of dynamic interaction that have already been referred to, in particular fishtailing and surging. By using a combination of relative and absolute positioning the best results are achieved.

A figure illustrating the essential elements of absolute and relative positioning is given below.

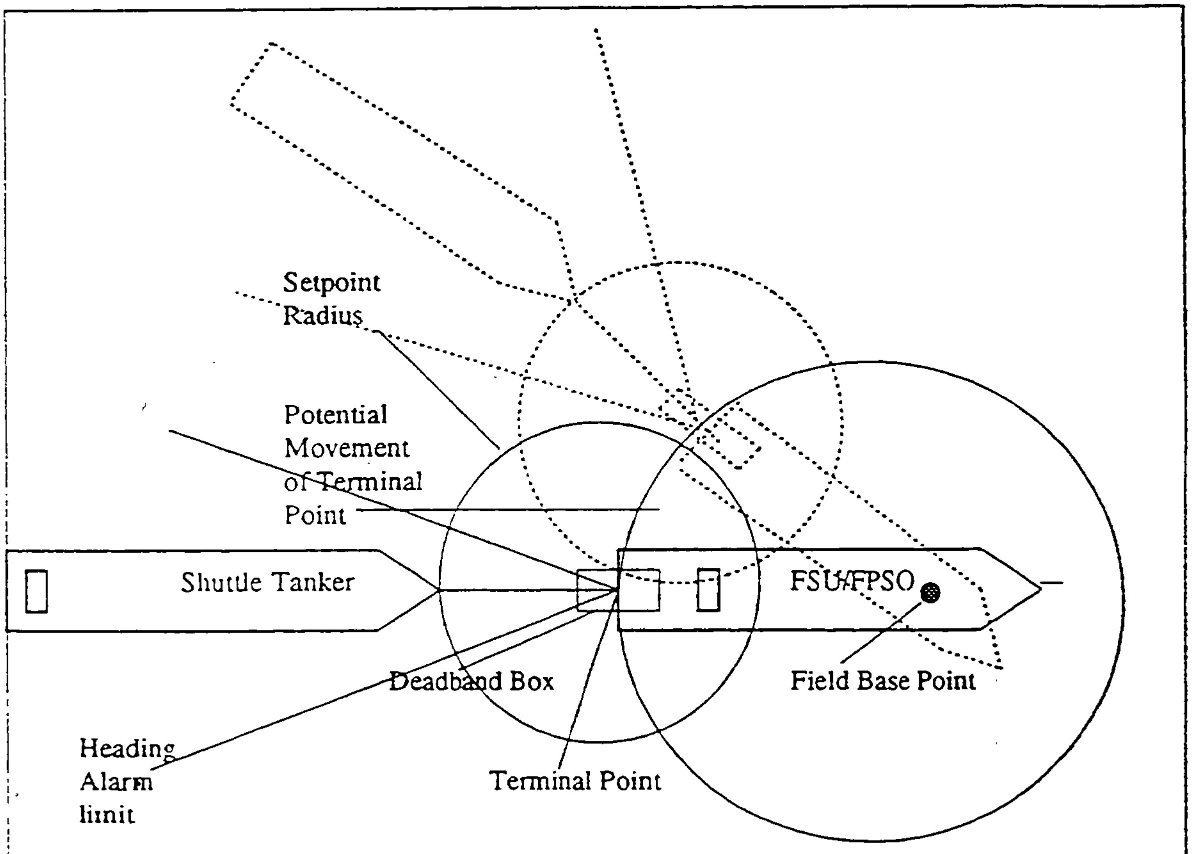


Fig. 5.11 - Absolute/Relative Position Keeping

The base condition is to position in absolute terms using a geo-stationary position reference system or systems. Position references used can be a LBL HPR system. Also DGPS can be used to provide a geo-stationary position. The heading of the FSU/FPSO is transmitted directly to the tanker as an input to the DP system. The field base point is generally at the point around which the FSU/FPSO rotates. Knowing the field base point it is possible to describe a circle around which the FSU/FPSO is liable to rotate. This is the larger of the circles. This circle provides the absolute dimensions of the position keeping logic. With a given heading for the FSU/FPSO and a measured nominal separation distance it is also possible to determine the position where the tanker's bow should be.

A terminal point is also selected. This is the point to which the tanker's DP system refers for relative positioning. The terminal point is the target position for the DP system. A deadband box is drawn around the terminal point. The target position is able to move within the deadband box without any corrective action from the DP control system. The position reference systems used for this relative aspect of positioning can be DARPS or Artemis. An arc of allowable heading movement is also incorporated into the positioning parameters. The reference used for the heading aspect of the positioning is the transmission of gyro heading from the FSU/FPSO to the shuttle tanker. The dotted lines in figure 5.11 show the dynamic nature of the system, so that as the FSU/FPSO rotates so shuttle tanker follows, both in absolute and relative perspectives.

The world's two most prominent manufacturers of shuttle tanker DP systems, Kongsberg Simrad and CEGELEC, are involved independently in the development of new control software based on the figure above. Specifically the software is intended to overcome the problems associated with fishtailing and surging at FSU/FPSO export facilities. As indicated above the approach is based on two aspects of control, viz., a) linking the heading of the shuttle tanker to the heading of the FSU/FPSO thus controlling yaw, and, b) introducing a 'deadband' or 'no movement box' into the excursion parameters, thus effecting control in both surge and also sway axes. The objective is to use the interfacing of the heading control to reduce fishtailing and to use the 'deadband' to reduce surging. A central principle of the control logic is to allow the tanker a considerable range of movement in all three axes; yaw, surge and sway, before the DP system begins the process of regaining the target position.

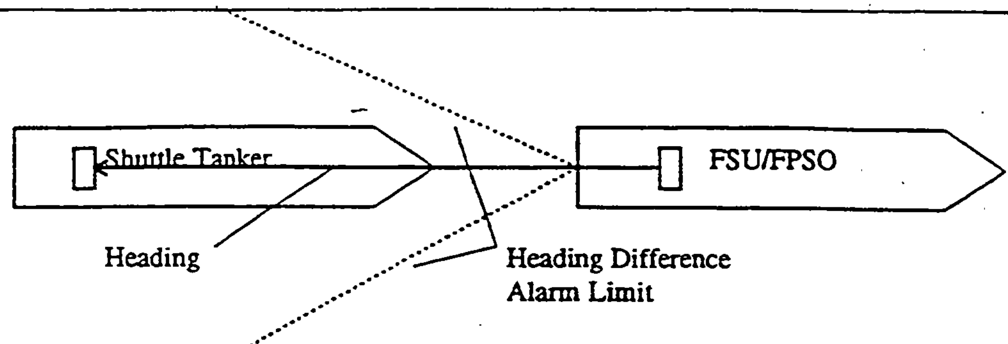
The two following sub-sections give a more detailed overview of the practical implementation of the principles described above. It must be remembered that the principles are dealt with independently and do not demonstrate the full dynamic nature of the interactions between the FSU/FPSO and the shuttle tanker.

5.4.1 Prevention of Fishtailing

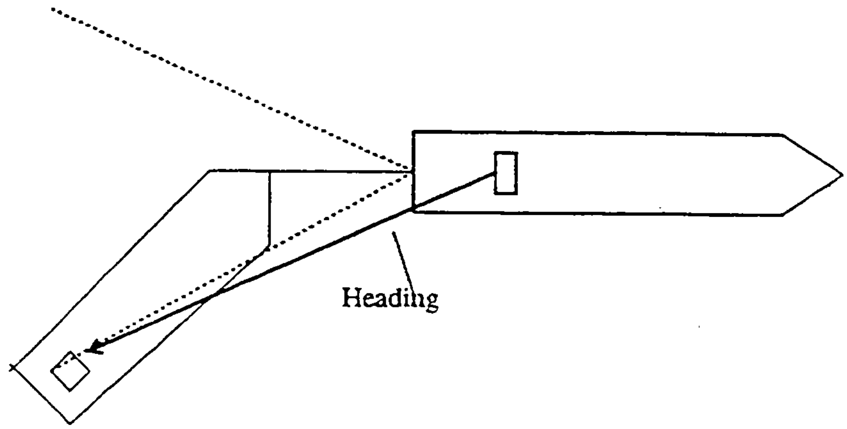
In order to establish heading control it is necessary for the heading of the FSU/FPSO to be linked with the heading of the shuttle tanker, so that that fluctuations in the FSU/FPSO heading can be transmitted to the shuttle tanker. The objective is that as the FSU/FPSO changes heading so the shuttle tanker's heading will follow. This requires there to be a means of transmitting the FSU/FPSO heading to the shuttle tanker and can be done by using the Artemis radio link or the UHF link used in the DARPS system, the important point being that the reference heading used by the shuttle tanker is input directly into the DP system from the FSU/FPSO. Also, where the FSU/FPSO remains relatively stationary in heading and where the shuttle tanker's heading begins to fluctuate, a heading difference will be detected and the heading control on the shuttle tanker will begin the process of bringing the shuttle tanker's heading back into line with that of the FSU/FPSO by exerting appropriate thrust.

By linking the two headings together in this way the shuttle tankers are no longer operating in accordance with the principle of weathervaning. Also, in implementing this type of heading control it is necessary for the shuttle tankers to have adequate transverse thrust capacity.

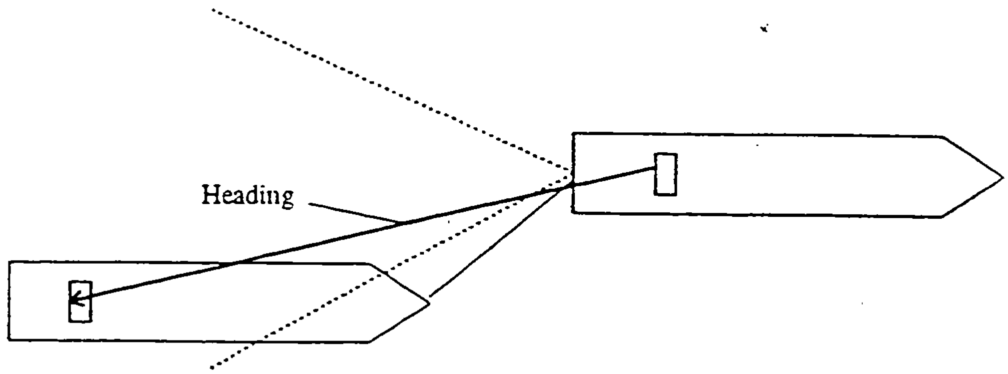
The basic geometry of the excursion limits can also be applied to shuttle tanker position as well as to heading, so that the bow of the tanker is kept within the sector limits.



The figure above shows the shuttle tanker and the FSU/FPSO in alignment. The heading information is transmitted from the FSU/FPSO to the shuttle tanker by the UHF link for the DARPS unit. Ideally there should also be a secondary transmittal of the heading information. This can be achieved via the Artemis link.



The figure above illustrates the shuttle tanker heading outside the heading alarm limits and the DP system responds by applying appropriate thrust to enable the tanker regain appropriate heading.

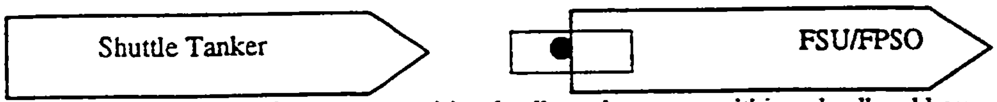


The figure above provides an additional application of the sector excursion limit. In this case the tanker's heading is in alignment with the FSU/FPSO, but the bow of the tanker is outside of the sector limits. This can also result in an alarm condition.

Fig 5.12 - Sector Excursion Limits

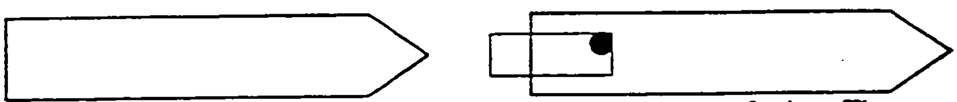
5.4.2 Prevention of Surging

The control methods used in the prevention of surging are based on the principle that the separation distance between the shuttle tanker and the FSU/FPSO is allowed to fluctuate within a predetermined box or deadband before any corrective action is taken to regain the target position. The series of figures below illustrates the sequence of movements. The figures below are intended to give an outline of the principles only and are not intended to provide a full explanation.



The black spot marks the target position. The target position is allowed to move within a deadband box.

The FSU/FPSO moves astern. The horizontal separation distance decreases. The target position is further towards the edge of the deadband box.



The FSU/FPSO moves further astern, decreasing the horizontal separation distance further. The target position is now at the extremity of the deadband box and the DP control system on the shuttle tanker begins to take action, initiating astern movement.

The shuttle tanker begins to move astern, increasing the horizontal separation distance and repositioning the target position in the middle of the deadband box.

Fig 5.13 - Basic Sequence of Movements in Deadband Box

5.4.3 Conclusion

The abbreviated descriptions of the improvements in DP system control of the FSU/FPSO - shuttle tanker interface are only intended to outline basic principles. The descriptions also serve to highlight the efforts currently being undertaken by the industry to overcome the worst problems of dynamic interaction. The above principles, based on a combination of absolute and relative positioning, are considerably in advance of earlier control principles, that were based on relative positioning and weathervaning. The success of the new techniques is not yet fully proven. Clearly techniques of this nature require the use of DP shuttle tankers with sufficient propulsion power to enable control to be exercised in the manner described above.

Practical implementation of the above techniques provides an early warning and early action system for the prevention of the worst excesses of fishtailing and surging. It is not considered that all associated problems will be totally overcome as a result.

6. REGULATORY REGIMES

Evidence and impressions gained during the course of this project indicate that the offshore industry sector has had to exercise a large measure of self regulation in respect of the establishment of suitable controls and standards for offtake operations, there being little in the form of guidance or regulation from national regulatory authorities and other relevant organisations.

There is nonetheless a regulatory framework within which this industry sector operates and it is subjected to a large number of external controls and influences from a number different quarters. To a large extent, however, such external control and influences are more likely to be concerned with traditional aspects of shipping regulation, such as hull and machinery classification items rather than those that are directly related to close proximity elements. There may be appropriate rules but they are not always applied across the shuttle tanker sector. For example, there are classification society rules for DP systems but they are not normally extended to DP shuttle tankers. It is only recently that some DP shuttle tankers have received a DP class notation.

This chapter is designed to give a brief overview of the roles played by each of the principal authorities and organisations involved in this sector. The information contained herein is neither definitive nor wholly comprehensive. It is designed to give an indication only of the regulatory framework.

6.1 Regulatory Authorities and Other Competent Organisations

IMO

IMO has issued the following instruments that are relevant to this industry sector;

- "STCW Convention and Code 1995" - setting out standards of competency for watchkeeping. The Code adopts the principle that competency assurance is achieved through vocational training and assessment schemes. Note that DP operations are not considered in the Code.
- "Guidelines for Vessels with DP Systems" - this is based on previous publications issued by NMD and certain classification societies in particular DNV.

IMO has adopted the following relevant guidelines;

- "IMCA Guidelines for the Training and Experience of Key DP Personnel"

National Regulatory Authorities

The NMD issued relevant rules for vessels engaged in DP operation on the Norwegian Continental Shelf. They are based on the IMO Guidelines. The NMD regulations do not stipulate the equipment class requirements for offtake operations.

Neither the UK HSE nor the UK MSA has issued regulation, statute or guidance in respect of DP shuttle tanker operations on the UKCS. In the UK the safety and integrity of offtake operations is considered in the context of the self regulatory aspects of the safety case regulations. It is the duty of the offshore operator (generally the oil company) of the offtake facility to reduce risks to ALARP. Evidence found during the course of this project indicates that safety case duty holders on the UKCS have not considered the marine and close proximity risks associated with offtake operations as thoroughly as the hydrocarbon risks associated with production processes.

Classification Societies

Most major classification societies have DP class notations. However, only a few DP tankers have been so classed. This is in contrast to the number of other DP ship types that are DP classed.

Industry Standards - Statoil

Without doubt the most powerful and influential standard bearer for the industry has been Statoil, the Norwegian state owned oil company. Statoil operates more export facilities and charters in more shuttle tankers than any other oil company. It is principally as a result of the high standards and the lead set by Statoil throughout this industry sector that the shuttle tanker offtake concept has been so successful in North West European waters over the last two decades.

Apart from a few pockets of resistance, Statoil standards are generally accepted throughout the sector. This includes standards on the following, which come from a document entitled "Statoil's General Requirements for Field Based Offshore Loading Facilities/Equipment.

1. Field Support Vessel - minimum towing capacity of 100 tonnes bollard pull - crew to be trained in emergency towing exercises at least twice per year - vessel to be in immediate vicinity of the shuttle tanker during the offtake.
2. Position Reference Systems - minimum of two different position reference systems to be operational and in use during offshore loading - following reference systems are acceptable, Artemis, HPR, DARPS.
3. Mooring Hawser/Separation Distance - where installed it is to have a breaking strain of a minimum of 57 tons - length of hawser to be minimum 80 metres when used with FSU/FPSO - length of hawser to be minimum 60 metres when used an loading buoy. Also a chafe chain of at least 9.5 metres length and 83mm diameter to be installed in the mooring system.
4. Environmental Limitations - when mooring the normative limitations are Hs = 4.5 metres, Hmax = 8.0 metres, wave period to be less than 15 seconds - during connect period the normative limitations are Hs = 5.5 metres, Hmax = 9.5 metres, wave period to be less than 15 seconds. The above values are to be considered in connection with wind and current conditions and whether the conditions are improving or deteriorating. The master is always at liberty to exercise his professional judgement on the basis of his analysis of the prevailing conditions. The following aspects are to be considered as deciding factors; potential wind changes in force and direction, tanker exposed to large rolling and pitching movements, combined effects of the wind/weather/current conditions.

Note that Statoil standards do not stipulate the equipment standard of the DP system required for DP shuttle tanker operations.

Statoil undertake test procedures for new shuttle tankers and also for tankers that are new to their operations. The test procedures incorporate DP testing but not to the same extent as testing and verification as required by the appropriate IMO DP Guidelines and also the IMCA DP Guidelines.

IMCA

IMCA has developed standards for the design and operation of DP vessels. Note that, in general, the IMCA standards have not been applied across the DP shuttle tanker sector. They are contained in the Guidelines for the Design and Operation of Dynamically Positioned Vessels.

OCIMF

The Oil Companies International Marine Forum is in the process of producing guidelines for this offshore sector. OCIMF have a successful tradition of setting standards across the industry that apply on a world-wide scale. Although their standards are not enforceable by regulation, in general, they are considered as an industry norm.

The OCIMF safety guidelines for offshore loading provide standards on the following topics;

- Health, Safety and the Environment
- Risk Management - including hazard identification, HAZOP studies, FMEAs, etc.
- Legislation and Shipping Standards
- Joint Operations Manuals
- Preliminary Assessment of Offtake Vessel
- Communications
- Pre-Arrival Safety Procedures and Equipment - including safety procedures, DP system, position reference systems, etc.
- Operations - including station keeping, hawser mooring DP method, fishtailing, DP capability plots, position reference systems, weather precautions, etc.
- Emergency and Contingency Planning - including deteriorating weather, power failures, communication breakdown, DP problems, mooring hawser failure, collision risks, emergency towing and standby vessel specification, etc.

INTERTANKO

It is understood that the tanker owner's principal industry organisation has set up a special committee for shuttle tanker operators. It is envisaged that the tanker owners, working in unison, will represent the interests of the shuttle tanker sector in matters of safety and environmental protection and will also be able to assist and influence the development and implementation of acceptable standards across the entire range of shuttle tankers.

In an effort to establish what is reasonably practicable in terms of risk reduction measures, consideration is given to hazardous events that are potentially liable to affect a shuttle tanker in a typical cargo offtake. Consideration is also given to environmental conditions that a tanker is likely to be subjected to. The base case risks for each hazardous event and condition are identified and are then considered against certain reasonably practicable risk reduction measures. The events and conditions are considered under three separate headings all of which apply inside the 500 metre zone of the FSU/FPSO export facility, viz.,

1. Approach and Berthing
2. Connected
3. Unberthing and Departure

The hazardous events and conditions considered in each case are as follows;

1. Main Propulsion Failure
2. Thruster Failure
3. Steering Gear Failure
4. Main Power or Electrical Failure
5. Position Control System Failure
6. Position Reference System Failure
7. Human Failure
8. FSU/FPSO Dynamic Interaction
9. Adverse Weather and Environmental Conditions
10. Fixed Obstructions, e.g. Pipelines, Installations, Wellheads, etc.
11. Other Marine Activity, e.g. Fishing Boats, Adjacent Rigs, Supply Boats, etc.

7.2.2 Tabulated Identification of Risk Reduction Methods

See over.

7. QUALITATIVE BEST PRACTICE

As is evident from the description and analyses set out in this report there are several types of export facilities that can be used at offshore locations, ranging from tandem offtakes, single point systems and mid-water systems. The list of types is large and grows larger every year. The risks associated with each type of facility are different. However, it is generally accepted that the close proximity risks are greatest where shuttle tankers are operating at FSU/FPSO export facilities. There are a number of reasons for this, including the following;

- Short separation distance from 47 to 120 metres, typically 80 metres - other than surface based SPM systems this is the shortest distance.
- Greatest dynamic interactions between FSU/FPSO and the shuttle tanker - problems related to different hydrodynamics characteristics and vessel movements.
- Greatest exposure of personnel, i.e. total combined complement of FSU/FPSO and shuttle tanker possibly in the region of 100 POB.
- Greatest hydrocarbon storage, potentially 150,000 dwt crude oil shared between the FSU/FPSO and the shuttle tanker.

As in the case of other types of export facility, if selecting the FSU/FPSO solution, the operator should ensure that the associated risks are reduced to the lowest reasonably practicable levels. This chapter sets out to indicate, in qualitative terms, what may be considered as reasonable in terms of risk reduction measures. To a large extent, because the risks are greatest at the FSU/FPSO - shuttle tanker interface, then there are grounds for implementing greater risk reduction measures at that interface than at others. Typically, this is likely to result in higher specification interface equipment, such as offtake hardware, systems and tankers, and is also likely to result in strict the exercises of procedural and management controls appropriate to the risk.

The measures referred to in this chapter are based in part on the experiences and practices of companies that participated in the project. They are also based on experiences and practices that are to be seen in other similar industry sectors. The measures referred to here are not the preserve of a single company but represent a combination of best practices across a wide spectrum of the offshore and shipping industries.

7.1 QUALITATIVE BEST PRACTICE

The method chosen to establish qualitative best practice is based on tabulated risk management techniques used in HAZOP. As indicated above the risk reduction measures originate from a number of different sources. There is no guarantee that the measures identified in the process described below cover the full range of available measures.

7.1.1 Base Case

For the purposes of this chapter it is assumed that we are dealing with an FSU/FPSO export facility, where offloads are carried out using shuttle tankers. This is the base case. However, certain decisions have to be made on a number of aspects of the operation, including the following; selection of tanker type, hawser and/or DP positioning, establishment of nominal separation distance, position reference systems, verification of tanker's fitness for purpose, human competency issues.

TANKER APPROACH & BERTHING (from 500 metre zone to FSU/FPSO)			
Hazardous Event/ Environmental Condition	**Description**	**Potential Loss**	**Risk Reduction Measures**
	Also during the berthing phase the failure of the steering gear should not have serious consequences since the tanker should be almost stopped over the ground.		implemented on immediate failure of main steering system. 3. Provide alternative heading control by main propulsion and thrusters.
Main Power or Electrical Failure	During approach and berthing phases loss of all main power is liable to have serious consequences.	Loss of power leading to loss of propulsion and position control. Collision with other ships and surface obstructions.	1. Provide tug assistance, as above. 2. Provide adequate redundancy in power generation and distribution, such as split switchboards. 3. Ensure prompt response of technical personnel to recover from failure. 4. Establish as far as is reasonably practicable the likely drift patterns of the tanker in various draft and environmental conditions, so that reasonable estimates of tanker movement can be made following irretrievable power failure.
Position Control System Failure	This refers to main automatic or semi automatic position control systems, such as DP systems or joystick/auto systems. During the approach phase, failure of the position control system should not have serious consequences. Given that there is adequate propulsion power and the means (emergency and normal) to control the propulsion output, it should still be possible to maintain navigable control of the tanker to effect a safe escape from the area. During the berthing phase the failure of the	Loss of position control. Collision with other ships and surface obstructions.	1. Provide tug assistance, as above. 2. Provide adequate alternative means of controlling position of the tanker, e.g. by providing an independent joystick back up to the DP control system.

TANKER APPROACH AND BERTHING

TANKER APPROACH & BERTHING (from 500 metre zone to FSU/FPSO)			
Hazardous Event/ Environmental Condition	**Description**	**Potential Loss**	**Risk Reduction Measures**
Main Propulsion Failure	During approach the failure of the main propulsion should not be a serious event. However, this will depend on the proximity of surface obstacles, such as rigs, etc. in the vicinity. Main propulsion failure is potentially more serious when the tanker is in final approach to the export facility and, especially when the tanker and the support vessel are in close proximity during the line pick up stage.	Tanker out of control and subject to environmental forces. Collision with export facility or other obstruction.	1. Provide tug assistance. Tug in close attendance during approach and in ready to tow condition. 2. Provide tanker with twin main propulsion, twin main engine, twin screw with separated auxiliaries. 3. Ensure that tanker main propulsion does not fail to full ahead or full astern. 4. Provide tanker with thrusters to provide auxiliary propulsion. Thrusters powered separately from main propulsion to avoid single point failure. 5. Ensure that main propulsion and thrusters, where fitted, are separated as far as possible, so that loss of main propulsion does not result in loss of thrusters.
Thruster Failure	During approach a thruster failure should not be a serious event. There should be sufficient main propulsion capacity to enable the tanker to maintain heading and position control. During the berthing phase and with the support vessel in close proximity the loss of the thrusters could have serious consequences, particularly during the line pick up phase.	Reduction in heading and transverse movement control. Collision with export facility, support vessel or other obstruction.	1. Provide tug assistance, as above. 2. Provide tanker with adequate thrusters fore and aft, grouped so that a single failure mode does not result in total loss of transverse thrust. 3. Ensure that thrusters do not fail to full ahead or full astern.
Steering Gear Failure	During approach the failure of the steering gear should not have serious consequences.	Loss of heading control.	1. Provide tug assistance, as above. 2. Provide emergency steering facility that can be

TANKER APPROACH & BERTHING (from 500 metre zone to FSU/FPSO)			
Hazardous Event/ Environmental Condition	**Description**	**Potential Loss**	**Risk Reduction Measures**
	main position control system is liable to have serious consequences, there being less room to manoeuvre using alternative means of control.		
Position Reference System Failure	During the approach phase the failure of the position reference systems should not have serious consequences. Even during the berthing phase the failure of the position reference systems should not have serious consequences since there should be adequate position and speed monitoring and control facilities still available to avoid serious consequences.	Loss of position reference input to the DP control system, where a DP system is fitted.	1. Provide at least two independent reliable position reference systems working on different principle with separate power supplies. 2. Ensure that the approach phase is carried out in periods of good visibility so that the position reference systems are not required for locating the targets. 3. Ensure that bridge personnel, master and officers, are competent in manoeuvring in close proximity to the export facilities.
Human Failure	Human failure can have serious consequences in all operational phases. During the approach and berthing phases there should be sufficient competent personnel in attendance on the bridge and in the engine room.	Maloperation, miscalculation or human error resulting in collision, loss of control and a variety of serious consequences such as total power failure.	1. Consideration and adoption of human error reduction strategies, including the following; 2. Ensure that there is adequate training and competency assurance of all key personnel involved in the operation, in line with IMO guidelines for key DP personnel. 3. Ensure that teamwork and understudy principles are in operation to cover for individual acts of maloperation. 4. Ensure that there is adequate planning and preparation for the operations.
FSU/FPSO Dynamic Interaction	This should not be a problem during the approach phase.	Generally not applicable.	

TANKER APPROACH & BERTHING (from 500 metre zone to FSU/FPSO)			
Hazardous Event/ Environmental Condition	**Description**	**Potential Loss**	**Risk Reduction Measures**
	During the mooring phase there should be sufficient opportunity to abort the operation if it is considered that the dynamic interaction is to be a problem.		
Adverse Weather and Environmental Conditions	Even before the approach phase there should be ample opportunity to ascertain environmental conditions, i.e. wind, waves, current, so as to establish the likely effects on the operation. It is possible that the environmental conditions may have greater impact on the support vessel if it is involved in transferring the pick up line to the tanker. Typically support vessels have a low profile main deck. The operation to transfer the pick up line inevitably involve personnel on the main deck.	Loss of control. Collision when in close proximity to the offtake facility, or more likely, with the support vessel.	1. Provide guidelines on environmental limits, such as wave height, swell period, speed and direction of currents and ensure that the guidelines are observed. Typical values are as follows for approach and berthing; Hs = 4.5 metres, Hmax = 8.0 metres, wave period not to exceed 15 seconds. 2. Ensure that the decision to proceed with approach and berthing operations is based on environmental criteria only and not subject to other influences, such as commercial pressure. 3. Where the shuttle tanker is operating at an unfamiliar export facility special care should be taken in assessing the impact of the environmental conditions. 4. Provide means of reducing the risk to personnel on the main deck of the support vessels, e.g. relocating the rocket firing from the main deck to the protected area of the forecastle. 5. Ensure that support vessels are adequately powered with effective protection for the crew and are suitably manned with competent crew

TANKER APPROACH & BERTHING (from 500 metre zone to FSU/FPSO)			
Hazardous Event/ Environmental Condition	**Description**	**Potential Loss**	**Risk Reduction Measures**
			members experienced in the specifics of the task.
Fixed Obstructions	Frequently there are fixed surface obstructions in the vicinity of export facilities. Such obstructions are liable to be fixed installations, anchored drilling or accommodation rigs. Such obstructions are liable to cause a hazard when the line of the tanker's approach is takes it close to the obstruction. Such obstructions are also liable to cause a problem in cases of loss of propulsion or loss of control, resulting in risk of collision. There are also liable to be restrictions when in the vicinity of pipelines or wellheads. Tanker movements over such seabed obstructions are generally restricted.	Collision with fixed obstruction.	1. Ensure that there is ample sea room for manoeuvring during the approach phase of the operation. Some operators have defined a closest point of approach to nearby installations and rigs of 1000 metres. Define an appropriate approach sector. 2. Ensure that there is always an escape route in the event of control or propulsion failure. 3. Use of tug to tow the tanker in the event of risk of collision.
Other Marine Activity	During the approach phase it is possible that the tanker may be affected by passing traffic, fishing activity or other offshore related operations, such as seismic activities. This may have an impact on the tanker's approach.	Delay. Collision.	1. Ensure that nearby traffic is given adequate warning and advice of approaching tanker. This can be done by marine traffic control, the support vessel or the tanker. 2. Ensure that proper notification of the facility is made through hydrographic and charting authorities. 3. Ensure that adequate generic information on offtake operation is given, wherever possible, to

TANKER APPROACH & BERTHING (from 500 metre zone to FSU/FPSO)			
Hazardous Event/ Environmental Condition	**Description**	**Potential Loss**	**Risk Reduction Measures**
			fishing authorities and others with legitimate reasons for operating in the vicinity.

TANKER CONNECTED			
Hazardous Event/ Environmental Condition	**Description**	**Potential Loss**	**Risk Reduction Measures**
			impact data. 10. Ensure that the FSU/FPSO export facility is protected against possible collision damage, using appropriate acceleration and impact data.
Thruster Failure	Failure of transverse thrusters will inevitably result in the reduction of transverse power with possible station keeping problems. The consequences will depend to a large extent on prevailing environmental conditions.	Loss of transverse control. Collision with FSU/FPSO - structural damage. Potential loss of containment of hydrocarbons - environmental damage	1. Equip tanker with twin main propulsion as above - twin propulsion systems can provide better turning moment than single screw systems. 2. Equip tanker with redundancy in transverse thruster capacity, e.g. two bow thrusters and two stern thrusters. Group thrusters together to reduce the number of single point failure modes, e.g. power the thrusters from separate sections of the switchboard. 3. Ensure that thrusters do not fail to full ahead or full astern - carry out FMEA and appropriate testing. 4. Ensure that there are adequate alarms to warn of thruster failure. 5. Ensure that there is appropriate operator intervention and effective emergency response to failure mode - training and competency. 6. Ensure that watchkeeping arrangements are adequate and that tanker position and propulsion are constantly monitored by operator. 7. Consider hawserless offtake operations to overcome potential problems with recoil action of hawser under tension. 8. Ensure that shuttle tanker forward section is protected against potential collision damage, using appropriate acceleration and impact data. 9. Ensure that the FSU/FPSO export facility is protected against possible collision damage, using appropriate acceleration and impact data.

TANKER CONNECTED

Foreword

As will be seen by inspection, much of the description and many of the risk reduction measures contained in the tables below are similar in content to those contained in the approach and berthing table. This is inevitable. However, there are elements in the tables below that are specific to the connected phase. As is explained in the tables the exposure to risk is greater in this phase than in any other phase.

TANKER CONNECTED			
Hazardous Event/ Environmental Condition	**Description**	**Potential Loss**	**Risk Reduction Measures**
Main Propulsion Failure	Failure of the main propulsion during the connected phase could have serious consequences, the severity of which will depend on the prevailing circumstances, in particular whether the failure mode results in an ahead movement that reduces the distance between the tanker and the FSU/FPSO. Even where the failure mode results in an astern movement, this can result in recoil action of the hawser under tension. The consequences will also depend on operator response.	Loss of ahead/astern control. Collision with FSU/FPSO - structural damage. Potential loss of containment of hydrocarbons - environmental damage	1. Provide tanker with twin main propulsion, twin main engine, twin screw and separated auxiliaries, as per IMO equipment class 2 standard. 2. Ensure that main propulsion does not fail to full ahead or full astern - carry out FMEA and appropriate testing. 3. Provide tanker with transverse thruster power to enable heading control in event of failure of main propulsion. 4. Provide additional azimuth thruster to enable ahead/astern movement independently of the main propulsion. 5. Ensure that there are adequate alarms to warn of main propulsion failure. 6. Ensure that there is appropriate operator intervention and effective emergency response to failure mode - training and competency. 7. Ensure that watchkeeping arrangements are adequate and that tanker position and propulsion are constantly monitored by operator. 8. Consider hawserless offtake operations to overcome potential problems with recoil action of hawser under tension. 9. Ensure that shuttle tanker forward section is protected against potential collision damage, using appropriate acceleration and

TANKER CONNECTED			
Hazardous Event/ Environmental Condition	**Description**	**Potential Loss**	**Risk Reduction Measures**
Steering Gear Failure	The consequences of failure of the steering gear will depend to a large extent on the type of system in use. Where the rudder is used to provide transverse thrust, as with high lift Becker type rudders, then its failure may result in loss of transverse control aft and subsequent instability in station keeping, especially when in DP control.	Station keeping instability with associated reduction in quality. Potential collision and station keeping difficulties.	1. Ensure that there is adequate emergency steering facility with straightforward change over. 2. Provide adequate transverse thrusters to give transverse propulsion. 3. Equip tanker with twin main propulsion as above - twin propulsion systems can provide better turning moment than single screw systems.
Main Power or Electrical Failure	Loss of all main power is liable to have serious consequences during the connected phase. The extent of the consequences will depend largely on the environmental conditions, where, in reasonable conditions, with the tanker in weathervaning mode, there may be no immediate harmful consequences. Power failure is likely to have serious consequences if occurring at times when there are other problems, such as dynamic interaction.	Loss of power leading to loss of propulsion and position control. Collision with FSU/FPSO. Potential loss of containment of hydrocarbons - environmental damage	1. Provide tanker with redundancy in terms of power generation and distribution, e.g. provision of Diesel electric power plant, separate or split switchboards, as per IMO equipment class 2. 2. Separate power generation from main engine, e.g. restrict use of power take offs from main propulsion, thus reducing the impact of failure of main engine. 3. Ensure that power generation and distribution plant are operated to achieve maximum safety during the connected phase and not for other reasons, such as to minimise running hours on plant.
Position Control System Failure	Failure of the position control system when in close proximity to the FSU/FPSO can have serious	Loss of position control.	1. Provide adequate alternative means of controlling position of tanker, e.g. by independent joystick, as per IMO DP equipment class 2 standards.

TANKER CONNECTED			
Hazardous Event/ Environmental Condition	**Description**	**Potential Loss**	**Risk Reduction Measures**
	consequences, the extent of which will depend on the nature of the failure and external influences, such as environmental conditions. When using DP there should be an alternative means of positioning control that will come into use on failure of the main control system. Typically this can be a joystick facility.	Collision.	2. Ensure that DP watchkeeping personnel are trained and competent in manual control in close proximity situations. 3. Ensure that there are appropriate emergency response procedures and that change over procedures are straightforward and adequately exercised.
Position Reference System Failure	Typically in DP operations the problems associated with position references are greater than with any other variable. When in close proximity it is inevitable that the quality of the position keeping will be heavily dependent on the quality of the input from the position references. Particular problems arise at FSU/FPSO locations because position keeping is relative rather than absolute, neither the FSU/FPSO nor the tanker being fixed in space. In DP control systems the loss of a position keeping reference input should not be immediately serious. Short term position stability should be provided by the mathematical model. However, long	Position keeping instability. Potential loss of position, followed by collision danger.	1. Provide at least two independent reliable position reference systems working on different principle with separate power supplies. When in close proximity it is advisable to operate with three position references. Appropriate systems are DARPS, Artemis, Fan Beam Laser and HPR. 2. Ensure that bridge personnel, master and officers, are adequately trained and competent in ship specific emergency procedures in the event of total failure of position reference inputs.

TANKER CONNECTED			
Hazardous Event/ Environmental Condition	**Description**	**Potential Loss**	**Risk Reduction Measures**
	term loss of position keeping input is untenable when in DP control.		
Human Failure	Human failure can have serious consequences in all operational phases. The exposure to risk is greater during the connection phase which can last typically from 18 to 36 hours, than during other shorter phases. The manning and watchkeeping philosophies are critical elements in the control of this human perspective. Efforts should be made to ensure that the manning and watchkeeping are designed to eliminate typical human related problems, such as fatigue, stress, over-familiarity, etc. Efforts should also be made to reduce the potential for human error. This should mean that proper consideration should be given to current human error reduction strategies. This is likely to involve special training and education.	Maloperation, miscalculation, human error can result in a variety of serious consequences, including collision.	1. Consideration and adoption of human error reduction strategies, including the following; 2. Ensure that there is adequate training and competency assurance of all key personnel involved in the operation, in line with IMO guidelines for key DP personnel. 3. Ensure that teamwork and understudy principles are in operation to cover for individual acts of maloperation. 4. Ensure that there is adequate planning and preparation for the operations.

TANKER CONNECTED			
Hazardous Event/ Environmental Condition	**Description**	**Potential Loss**	**Risk Reduction Measures**
FSU/FPSO Dynamic Interaction	This is potentially the most serious on-going problem affecting shuttle tanker operations at FSU/FPSO export facilities. The major problems are linked to fishtailing and surging. Experience shows that, OTBE, the greater the separation distance the less problems there are with surging. Also experience shows that problems of fishtailing are reduced where the FSU/FPSO facility has its own heading or even DP control, and where the heading of the FSU/FPSO is directly input to the tanker's DP system as a reference.	Collision. Pollution.	1. Establish adequate nominal horizontal separation distance at the shuttle tanker - FSU/FPSO interface. Typical values are 80 metres for the FSU/FPSO - shuttle tanker interface. 2. Provide the FSU/FPSO with heading that is input directly to the tanker's DP system. 3. Provide FSU/FPSO with a DP control system, thus assisting the maintenance of alignment with the tanker during tandem operations. 4. Ensure that there are adequate procedural controls in place aimed at identifying the onset of such problems of dynamic interaction and dealing with them at an early stage. 5. Ensure that watchkeeping personnel are adequately trained in dealing with problems associated with the dynamic interaction. 6. Ensure that watchkeeping personnel understand the problems associated with dynamic interaction. 7. Carry out mathematical modelling and/or tank testing to establish dynamic interaction at various offtake facilities and with different tankers, at various drafts.
Adverse Weather and Environmental Conditions	Inevitably environmental conditions have a significant influence on the conduct of offtake operations, especially in the North Sea and the Atlantic Frontier. As a result all shuttle tankers and FSU/FPSO export facilities must make adequate provision for occasions when	Potential Collision	1. Establish environmental criteria for the connect phase of the operation. Typical values are Hs = 5.5 metres, Hmax = 9.5 metres, wave period not to exceed 15 seconds. 2. Ensure that provision is made for other environmental conditions, such as current, cross sea and swells. 3. Ensure that decision making processes are free to respond to environmental conditions and are not subject to influence by other external aspects, such as commercial pressure.

TANKER CONNECTED			
Hazardous Event/ Environmental Condition	**Description**	**Potential Loss**	**Risk Reduction Measures**
	environmental conditions are adverse. Environmental conditions play a significant part in creation of dynamic interaction problems.		4. Where the shuttle tanker is operating at an unfamiliar export facility special care should be taken in assessing the impact of the environmental conditions. 5. Carry out tank testing and/or mathematical modelling to determine acceptable environmental limits. 6. Ensure that there is accurate monitoring of environmental conditions, in particular, adequate wave height measurement, possibly by recorder buoy.
Fixed Obstructions	When in the connect phase there should not be a significant problem with other fixed installations. The nearest surface obstruction will be the adjacent FSU/FPSO. However, where there are subsea pipelines, well heads and even surface obstructions, e.g. fixed installations in the near vicinity this may give rise to restricted entry sectors from which the shuttle tanker and FSU/FPO are excluded.	Collision.	1. Ensure that restricted sectors are well defined and understood and clearly marked on charts. 2. Ensure that there are clear field instructions on actions to be taken in event of entering into a restricted sector. 3. Ensure that adequate provision is made for the management of shuttle tanker - FSU/FPSO restricted sectors. In many cases, this is done, by using the support vessel and placing it on various stages of alert during the offtake. E.g. if the tanker is directly upwind and current of a surface installation, then some operators require the support vessel to be attached by tow wire as a precaution. 4. Provide standby support vessel in ready to tow condition.
Other Marine Activity	During the connected phase there should not be a significant problem with other marine activity.		1. Monitor the surrounding sea area, possibly by visual and radar watch from the standby support vessel. 2. Ensure that proper notification of the facility is made through hydrographic and charting authorities.

TANKER CONNECTED			
Hazardous Event/ Environmental Condition	**Description**	**Potential Loss**	**Risk Reduction Measures**
	Where there is a standby support vessel it should be monitoring the surrounding sea area to ensure that other ships remain clear of the vicinity.		3. Ensure that adequate generic information on offtake operation is given, wherever possible, to fishing authorities and others with legitimate reasons for operating in the vicinity.

UNBERTHING & DEPARTURE

Many of the elements in the unberthing and departure phase are virtually the same as in the approach and berthing phase. In order to avoid repetition only the elements that are particular to the unberthing and departure phase are considered in the following table.

UNBERTHING & DEPARTURE (from FSU/FPSO to 500 metre zone)			
Hazardous Event/ Environmental Condition	**Description**	**Potential Loss**	**Risk Reduction Measures**
Main Propulsion Failure	N/A		N/A
Thruster Failure	N/A		N/A
Steering Gear Failure	N/A		N/A
Main Power or Electrical Failure	N/A		N/A
Position Control Failure	N/A		N/A
Position Reference System Failure	N/A		N/A
Human Failure	N/A		N/A
FSU/FPSO Dynamic Interaction	There may be occasions when the unberthing and departure are considered necessary as a result of the dynamic interaction between the shuttle tanker and the FSU/FPSO.	Collision.	1. Ensure that there are appropriate withdrawal criteria for the tanker and that masters and officers exercise appropriate competent judgement. 2. Provide ship and field specific training for masters and officers.
Adverse Weather and Environmental Conditions	There are many occasions when unberthing and departures are carried out at times of adverse weather. In many cases it is the adverse weather that precipitates a disconnection and departure. Due attention should always be given to caring	Collision Injury to personnel on board support vessel.	1. Ensure that adverse weather criteria are established for the ship and field. 2. Make provision for the support vessel, ensuring that it is not required to carry out handling operations in environmental conditions that are beyond its capabilities, paying particular

UNDERTHING & DEPARTURE (from FSU/FPSO to 500 metre zone)			
Hazardous Event/ Environmental Condition	**Description**	**Potential Loss**	**Risk Reduction Measures**
	for the loading hose, hawser, messenger and pick up arrangements, bearing in mind, that almost inevitably, the support vessel will be used to lay out the system after the departure of the tanker.		attention to the risks to personnel on working deck of the support vessel.
Fixed Obstructions	Difficulties may arise on the release of the tanker when there is an obstruction, such as drilling rig or offshore installation in the way of the direction of departure.	Collision.	1. Ensure that the tanker always has an achievable escape route to clear all the obstructions in the vicinity.
Other Marine Activity	Safe departures can be jeopardised by the presence of marine activity in the vicinity. This can be fishing activity and/or offshore related operations.	Collision	1. Monitor the marine activity prior to unberthing and departure. Visual and radar monitoring can be carried out by the support vessel and/or the tanker. 2. Broadcast appropriate warning messages on radio.

EXECUTIVE SUMMARY

This report necessarily covers a wide range of subject matter. To assist the reader the following summary of salient findings has been prepared:

"The greatest single marine risk is that of collision between the FSU or FPSO and the offtake tanker. Where, as in most cases, the positioning of the offtake tanker is controlled by DP then the reliability and effectiveness of the DP system and its peripherals are of utmost importance." - 1.3.5.

"Effective management of the pump room can reduce the risks significantly, so much so, that some tanker operators have still to experience their first pump room accident." - 2.4.1.

"Clearly, a telemetry system is a safety critical element in the cargo transfer system. For continuous safe operations it should have in-built redundancy and be thoroughly reliable. Its operation should be controlled by effective management and strictly imposed procedures." - 2.4.2.

"To bring shuttle tankers more into line with contemporary DP vessel thinking the most technologically advanced shuttle tankers are fitted with twin engines in separate engine rooms, generally allowing full redundancy of main propulsion." - 2.4.4.

"CPPs are the preferred form of main propulsion on shuttle tankers....... Without bow thrusters it is very difficult to maintain the heading of a tanker, especially when in light condition...." - 2.4.5.

"The most secure and effective way of ensuring power supply from generating plant is to install independent generating sets each capable of independent operation and, where necessary, with separation of auxiliaries, including fuel supplies, lubricating and cooling systems." - 2.4.6.

"As seen from the tables the control location for the most recent tanker is on the navigating bridge whereas it is on the forecastle for the other generation tankers. This change of location is generally considered to be a risk reduction measure.......It is now generally recognised that the navigating bridge is a safer location." - 2.4.7.

"A small number of offshore oil operators are convinced of the merits of non-DP shuttle tankers and are not inclined to alter their opinion on grounds of safety, environmental protection or productivity. It cannot be gainsaid that successful offtake operations continue to be carried out by non-DP tankers." - 2.4.8.

"There is no comparable forum for DP shuttle tanker sector, although it is understood that the tanker owners (INTERTANKO) have formed a shuttle tanker section that can conceivably undertake the same kind of activity as is currently undertaken by IMCA on behalf of other DP vessel owners." - 3.3.1.

"Question to industry - "What area or areas of shuttle tanker operations cause the greatest concern in terms of safety and/or environmental pollution and how are they best addressed?" - Answers:- Tanker positioning and control, tanker human resources, dynamic interaction, tanker propulsion, operational management, environmental preparation, support vessel, tanker power generation." - 3.6.2.

"This issue of how to deal with emergencies is further complicated by problems associated with identifying when the DP shuttle tanker is in an emergency situation. There are examples when single engine DP shuttle tankers in close proximity to an FSU/FPSO, go from full ahead to full astern during periods of dynamic interaction. Failure of the main propulsion during an ahead or an astern movement could have serious consequences." - 3.6.3.

"This standard of manning is not necessarily repeated on a DP shuttle tanker, even although it might be only a 50 or 60 metres away from the FSU/FPSO and the associated risks greater by several magnitudes. It would be reasonable to suggest that similar standards of permanent watchkeeping be employed on DP shuttle tankers." - 3.6.3

"It appears that the typical arrangement for DP shuttle tankers is to use the DP control system as an alarm system, thus cutting back on the console monitoring and potentially losing the advantages that are clearly associated with effective DP watchkeeping." - 3.6.3

"The standards of DP verification, testing and trials generally required by the DP shuttle tanker sector appear to be less comprehensive than for other types of DP ships." - 3.6.3.

"…….the more important strand in this concern relates to the way in which on a large number of DP shuttle tankers, the hands on operation of the DP system remains the preserve of the master….. out of step with current principles of effective bridge management……. the most effective methods of managing human resources in critical activities such as in navigation and manoeuvring are based on good team work……. It is apparent that these principles are not to the fore in the operation of DP shuttle tankers." - 3.6.3.

" …….apparent that there are occasions when additional commercial pressures are brought to bear on the senior personnel involved in the operation." - 3.6.3.

" ……the environmental profile for the sea area to the West of Shetland is somewhat different to that of the North Sea……. this combination of forces is likely to have an adverse effect on the manoeuvrability and control of the shuttle tanker as well as on the dynamic interactions between the FSU/FPSO and the shuttle tanker." - 3.6.3.

"It is generally accepted that a support vessel is in attendance for the duration of the offtake…… at the connection phase and the support vessel remains in relative close proximity to the shuttle tanker………for many duty holders the close attendance of the support vessel is considered as a major risk reduction measure…….. no comparable guidelines for the assessment of suitability of support vessels." - 3.6.3.

"……most DP shuttle tankers still use HO. It is a widely held view that a failure in a HO system is more liable to result in subsequent failure of standby machinery to start." - 3.6.3.

"One of the most important points to emerge from this chapter is that the reporting and recording of DP shuttle tanker accidents and incidents are neither organised nor administered in a manner that is capable of bringing maximum benefit to the participants in the industry…….. benefits to be gained from a sector specific accident and incident reporting scheme." - 3.7.

"As indicated in Chapter 2 their numbers have increased markedly over the last two decades and there are now in excess of twenty operating on the North West European Continental Shelf, principally in Norwegian and UK waters……. Considerable progress has been made in recent years to improve the reliability and effectiveness of DP control systems in general" - 4.

"CPPs have the advantage over fixed pitch systems (FPP) that their speed of response is considerably swifter." - 4.3.1.

"OTBE the risks associated with offtake operations at FSU/FPSOs are generally considered to be greater than at SPMs and significantly greater than at sub-sea offtakes such as OLS and STL systems." - 4.6.3

"Training and competency issues have been recognised as key elements in the management of DP operations for many years........ results from 1993 indicate that 25% of all DP incidents were caused principally by operator error." - 4.7.

"Successful dynamic positioning is a product of a combination of essential elements, a major one being the human perspective" - 4.7.1.

"Clearly, to use large shuttle tankers, some of 150,000 tonnes deadweight capacity and to operate them in close proximity to similar sized FSU/FPSOs at offshore production locations in harsh environmental conditions does present a palpable risk of collision........One of the major influencing factors in any close proximity situation is separation distance." - 5.1.1.

".....there are two specific dynamic interactions that give particular cause for concern, viz., fishtailing and surging." - 5.7.2.

"The world's two most prominent manufacturers of shuttle tanker DP systems, Kongsberg Simrad and CEGELEC, are involved independently in the development of new control software based on the figure above." - 5.4.

"Evidence and impressions gained during the course of this project indicate that the offshore industry sector has had to exercise a large measure of self regulation in respect of the establishment of suitable controls and standards for offtake operations, there being little in the form of guidance or regulation from national regulatory authorities and other relevant organisations." - 6.

"......it is generally accepted that the close proximity risks are greatest where shuttle tankers are operating at FSU/FPSO export facilities. There are a number of reasons for this, including the following:

- Short separation distance from 47 to 120 metres, typically 80 metres - other than surface based SPM systems this is the shortest distance.
- Greatest dynamic interactions between FSU/FPSO and the shuttle tanker - problems related to different hydrodynamics characteristics and vessel movements.
- Greatest exposure of personnel, i.e. total combined complement of FSU/FPSO and shuttle tanker possibly in the region of 100 POB.
- Greatest hydrocarbon storage, potentially 150,000 dwt crude oil shared between the FSU/FPSO and the shuttle tanker." - 7.

ABBREVIATIONS USED IN THE REPORT

ABS	American Bureau of Shipping
AC	Alternating Current
ADP	Automatic Dynamic Positioning
AGC	Automatic Gain Control
ALARP	As Low as is Reasonably Practicable
ALC	Articulated Loading Column
ALP	Articulated Loading Platform
BLS	Bow Loading System
BRM	Bridge Resource Management
CALM	Catenary Anchor Leg Mooring
CCR	Cargo Control Room
CCTV	Closed Circuit Television Monitoring
COT	Crude Oil Tank
CPP	Controllable Pitch Propeller
DARPS	Differential Absolute and Relative Positioning System
DG	Diesel Generator
DGPS	Differential Geo Positioning System
DNV	Det Norsk Veritas
DO	Diesel Oil
DP	Dynamic Positioning
DPS	Dynamic Positioning System
DPVOA	Dynamic Position Vessels Owners Association
dwt	Deadweight Tonnes
ECU	Electronic Control Unit
EPT	Early Production Test
ERO	Electrical Radio Officer
ESD	Emergency Shutdown
ETO	Electrical Technical Officer
EWT	Extended Well Test
F/B	Feedback
FMEA	Failure Modes and Effects Analysis
FPP	Fixed Pitch Propeller
FPSO	Floating Production Storage and Offloading
FSU	Floating Storage and Unit
FSVAD	Flag State Verification and Acceptance Document
GPS	Geo Positioning System
HAZOP	Hazard and Operability Study
HC	Hydrocarbon
HF	High Frequency
Hmax	Maximum Wave Height
HO	Heavy Oil
HP	High Pressure
hp	Horse Power
HPR	Hydro Acoustic Position Reference
Hs	Significant Wave Height
HSE	Health and Safety Executive
HV	High Voltage
ID	Internal Diameter
IMCA	International Marine Contractors Association

IMO	International Maritime Organisation
INTERTANKO	International Tanker Owners Organisation
LBL	Long Base Line
mA	Milli Amps
MAIB	Marine Accident Investigation Branch
MF	Medium Frequency
MHz	Mega Hertz
MS	Merchant Shipping
MSA	Marine Safety Agency
MSC	Maritime Safety Committee
NI	Nautical Institute
NMD	Norwegian Maritime Directorate
NPD	Norwegian Petroleum Department
NUC	Not Under Command
OCIMF	Oil Companies International Marine Forum
OIM	Offshore Installation Manager
OLS	Offshore Loading System
OSC	Offshore Safety Case
OSD	Offshore Safety Division
OTBE	Other Things Being Equal
OTC	Offshore Technology Conference
PED	Petroleum Energy Division
POB	Persons on Board
PPE	Personal Protective Equipment
PRC	Pseudo Range Correction
PRS	Position Reference System
QA	Quality Assurance
QC	Quality Control
QRA	Quantified Risk Analysis
RIDDOR	Reporting of Injuries, Diseases and Dangerous Occurrences Regulations
SAL	Single Anchor Loading
SAP	Single Anchor Production
SBM	Single Buoy Mooring
SDP	Simrad Dynamic Positioning
SDS	Stern Discharge System
SPM	Single Point Mooring
SSBL	Super Short Base Line
STCW	Standards of Training, Certification and Watchkeeping (IMO)
STL	Submerged Turret Loading
SW	Short Wave
TCMS	Tripod Catenary Mooring System
TEMPSC	Totally Enclosed Motor Propelled Survival Craft
UKCS	United Kingdom Continental Shelf
UKOOA	United Kingdom Offshore Operators Association
UMS	Unmanned Machinery Space
V	Volts
VQ	Vocational Qualification
VRS	Vertical Reference Sensor
VRU	Vertical Reference Unit
WBT	Water Ballast Tank
Wx	Weather

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