Report on the investigation of the

impact with the quay by

the passenger ro-ro ferry

P&OSL Aquitaine

at Calais

on 27 April 2000

Marine Accident Investigation Branch
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The fundamental purpose of investigating an accident under these Regulations is to determine its circumstances and the cause with the aim of improving the safety of life at sea and the avoidance of accidents in the future. It is not the purpose to apportion liability, nor, except so far as is necessary to achieve the fundamental purpose, to apportion blame.

CONTENTS

GLOSSARY OF ABBREVIATIONS AND ACRONYMS

BST	-	British summer time
CPP	-	Controllable pitch propeller
ECDIS	-	Electronic Chart Display and Information System
ECR	-	Engine Control Room
ECS	-	Electronic chart system
FAOP	-	Full away on passage
ICS	-	International Chamber of Shipping
ISM	-	International Safety Management
MAIB	-	Marine Accident Investigation Branch
MGN	-	Marine Guidance Note
OOW	-	Officer of the watch
PEC	-	Pilot Exemption Certificate
P&OSL	-	P&O Stena Line
PTO	-	Power take off
Ro-Ro	-	Roll on, roll off
rpm	-	Revolutions per minute
VDR	-	Voyage Data Recorder
VHF	-	Very high frequency
VTS	-	Vessel traffic services

SYNOPSIS

On 27 April 2000 at about 1000 BST, P&O Stena Line (P&OSL) notified the Marine Accident Investigation Branch (MAIB) that the passenger ro-ro ferry *P&OSL Aquitaine* had struck No 7 berth in Calais. Many passengers were injured and both the berth and the vessel had sustained damage. MAIB inspectors arrived at the scene of the accident later that day.

The vessel is a 163.6m ro-ro passenger ferry built in 1992. Her registered owners are Stena Ferries Ltd and she was chartered to P&OSL on 21 April 1999. In October that year the vessel underwent an extensive refit, and she entered service on the Dover to Calais route in November 1999.

P&OSL Aquitaine left Dover at 0817 BST on 27 April 2000, bound for Calais, France. On board were 1241 passengers and 123 crew. After she had passed through the Calais port entrance the master realised he was going faster than normal. Despite putting the two combinators to select astern pitch on both propellers, only the starboard propeller actually responded to the command. The failure of the port propeller to respond was not noted by the bridge team. As a result, the master was unable to prevent the vessel from striking the berth at a speed of about 7 knots.

At the time of impact, many passengers were standing up ready to disembark, while others were making their way down on to the car deck. 180 passengers and 29 crew were injured. The vessel was taken out of service and dry docked, returning to service in June 2000 on the same Dover/Calais run.

A number of factors contributed to the accident including:

- Loss of control of the port controllable pitch propeller (CPP) because of the damaged port engine-driven oil pump;

- The chief engineer's failure to inform the master that there was a potential fault with the port CPP system, and the bridge team's lack of awareness of the problem.

Recommendations have been made which, if implemented, will reduce the possibility of a similar accident happening again.

SECTION 1 - FACTUAL INFORMATION

1.1 PARTICULARS OF *P&OSL AQUITAINE* AND ACCIDENT

VESSEL DETAILS

Name	:	*P&OSL Aquitaine*
Registered owner	:	Stena Ferries Ltd
Manager(s)	:	P&O Stena Line
Port of registry	:	Dover
Flag	:	UK
Type	:	Ro-ro passenger
Built	:	Temse, Belgium 1992
Classification society	:	Lloyd's Register of Shipping
Length overall	:	163.6m
Gross tonnage	:	28833
Passenger capacity	:	1850
Engine power and/or type	:	4 Sulzer 8ZAL40S diesel engines
Service speed	:	21 knots
Other relevant info	:	2 x 1512kW bow thrusters, twin screw, LIPS CPP, twin rudder
Accident details		Collision with the quay
Time and date	:	0939 BST 27 April 2000
Location of accident	:	Berth No 7 Calais, France
Persons on board	:	1364 (1241 passengers and 123 crew)
Injuries/fatalities	:	209 injured, no fatalities
Damage	:	Bulbous bow and bow apron badly damaged

P&OSL Aquitaine (photograph courtesy of P&O Stena Line)

1.2 BACKGROUND

P&OSL Aquitaine is a motor passenger ro-ro ferry operated by P&O Stena Line on the Dover to Calais service. She was built for Belgium owners in 1992 in Temse Belgium as the *Prins Filip*. Briefly renamed *Stena Royal* in 1998, she became *P&OSL Aquitaine* in 1999.

The registered owners are Stena Ferries Ltd and she was chartered to P&O Stena Line (P&OSL) on 21st April 1999. From then until October 1999 *P&OSL Aquitaine* was operated on the Dover/Zeebrugge route, carrying commercial vehicles and freight. After an extensive refit at Falmouth in October, she entered service on the Dover to Calais route in November with a passenger capacity of 1850.

In March 1998, the two former competitors, P&O and Stena Line, amalgamated to form P&O Stena Line, to compete more effectively against the Channel Tunnel route. The company operates seven ferries on the Dover/Calais route.

P&OSL Aquitaine has passenger cafés, shops, bars and restaurants and stairways connecting the various passenger decks. Passengers have access to several outside decks. For safety reasons during the crossing, passengers are not allowed on the car decks. Before returning to their vehicles, they must wait for an announcement permitting them to do so just before arrival.

P&OSL Aquitaine sails almost continuously between Dover and Calais, with a few hours "lay over" daily. During the busiest periods, turnaround time can be as little as 45 minutes. P&OSL are at their busiest carrying passengers in the summer and during holiday periods. The accident occurred during the Easter week holidays when 1241 passengers and 123 crew were on board. At the time, the vessel's sailing schedule consisted of three round trips during the day, and two at night.

1.3 NARRATIVE OF EVENTS

1.3.1 <u>The previous passage, Calais to Dover 27 April 2000</u>

The main engines were started at about 0535 (BST) and *P&OSL Aquitaine* left Calais bound for Dover at 0545 (BST). On the engine room watch were the 0600 to 1400 fourth engineer watchkeeper, the motorman and the second engineer. The second engineer was covering the stand-by watch for the chief engineer who was having breakfast. The 0600-1400 third engineer watchkeeper came on duty at about 0550 as the vessel was leaving.

During the stand-by, the watchkeepers observed that the port CPP electrical stand-by pump had cut in. There was no apparent reason for it having done so. Since the vessel was manoeuvring for departure Calais, it was set to run continuously to ensure that no further problems would be encountered during the departure. The third engineer went down to the gearbox room to check if there was a problem with the port CPP system. It takes about 6 to 7 minutes to reach the space since four closed watertight doors have to be opened first.

Once in the space, he heard what he thought to be hydraulic knocking and rattling, which seemed to come from each side of the gear-driven CPP pump. The pipes were warm. He assumed the noise and heat was the result of the stand-by pump running at the same time as the gear-driven CPP pump. He felt the underside of this pump and, although the oil inside was warm, he could not feel any knocking from the pump itself. Once the vessel was full away, the CPP port electrical stand-by pump was stopped manually, and the starter switch reset to automatic restart. The noise stopped at the same time. The pipes started to cool down almost immediately.

The third engineer then found the gear-driven CPP pump delivery pressure to be about 65 to 79bar and the system control pressure (return pressure) at 6.8 to 7.0bar. He compared these readings with the starboard CPP system. The delivery pressure gauge for this side was not working, so he replaced it with that of the starboard stand-by delivery pump pressure gauge. He then noted the starboard CPP gear-driven pump delivery pressure, and the starboard system control pressure was 75 to 80bar and 8bar respectively. The pressures were higher than the port side, but still well within operational limits.

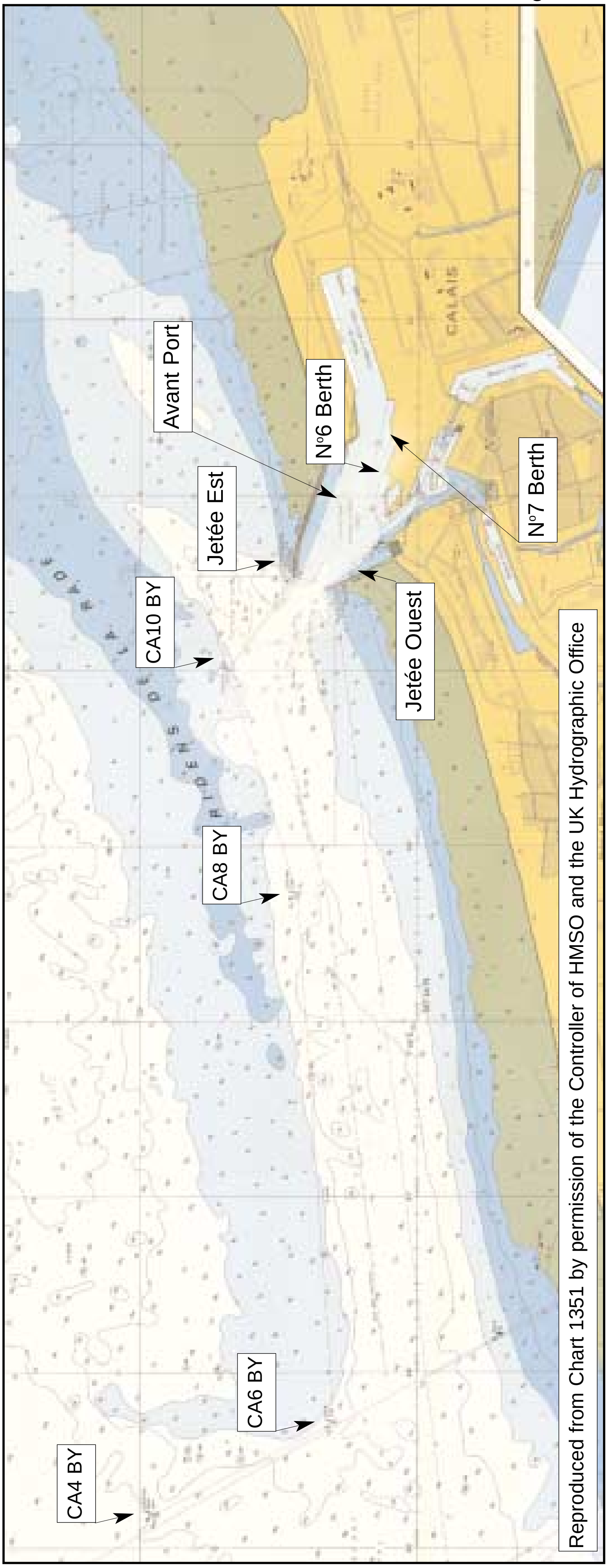
Thinking that the setting of the port CPP back pressure valve (PSV3) had altered because of the hydraulic knocking, he adjusted the valve to increase the pressure to match that of the starboard. He also checked the oil temperature, which he found to be normal at about 38° to 40°C.

The third engineer returned to the ECR to report to the second engineer. The third engineer deduced that, although there had been some vibration in the pipes and the oil was warm, this was because both pumps were running.

Before the second engineer left the engine room, the third engineer continued to maintain a close watch on the system. Following his departure from the engine room, the second engineer met the chief engineer and advised him about the electrical stand-by pump cutting in on departure from Calais, and actions taken.

For the vessel's arrival at Dover the chief engineer was on duty in the ECR, with the third and fourth engineers. While berthing at Dover, the port CPP electrical stand-by pump cut in several times. He knew immediately that the stand-by pump had cut in, since a warning light illuminated on the ECR console and an audible alarm sounded on the VDU. The first time the pump cut in, the chief engineer sent the third engineer to investigate. In the meantime, and on each occasion the stand-by pump cut in, the chief engineer stopped it and reset the switch to automatic restart. When the third engineer returned from inspecting the port CPP machinery and pressures, he reported having found nothing

Figure 1



Reproduced from Chart 1351 by permission of the Controller of HMSO and the UK Hydrographic Office untoward. The chief engineer therefore assumed that there had simply been momentary drops in pressure from the shaft-driven pump, which occasionally takes place during rapid changes from ahead to astern pitch when manoeuvring. Even though the third engineer had not noticed anything untoward during his inspection, the decision was taken to inspect the suction filter on the delivery side once the vessel had berthed at Dover. As when departing Calais, the third engineer noted that the system piping was vibrating when both the stand-by and shaft-driven pumps were running at the same time.

1.3.2 In Dover

Once alongside in Dover, the third engineer checked the suction filter on the suction side only, of the shaft-driven pump. It was clean. While doing so he took every precaution to ensure a minimum loss of oil, to prevent the possibility of introducing air into the sys tem. When the filter was replaced, he primed the system and started the stand-by pump locally to check that there was sufficient pressure in it.

For departure Dover, the chief engineer was once again on duty in the ECR. The second engineer was also present. The third engineer informed the chief engineer that the filter had been checked and had been found to be clean. He reported the adjustment he had made to the control valve for the back pressure on the port CPP system during the previous passage.

Having ascertained from the duty engineers that everything in the machinery space was ready for departure, in accordance with standard procedure, the chief engineer reported to the master that the engineering plant was ready for the vessel to proceed to sea. The chief engineer had not informed the master of the electrical stand-by pump cutting in on departure Calais, or on arrival at Dover, or that he was investigating an unsolved problem with the port CPP system.

1.3.3 Events in the engine room during the Dover to Calais crossing

P&OSL *Aquitaine* left Dover bound for Calais at 0817. During the first 8 minutes of manoeuvring from berth, the port CPP stand-by pump cut in on several occasions. The third engineer again checked the system pressures and found them to be normal. The chief engineer assumed that the stand-by pump was cutting in on this occasion, possibly because air had entered the system when the third engineer had removed the suction filter for cleaning. He expected this air eventually to vent to atmosphere through the header tank. On returning to the ECR, the second and third engineer informed the chief engineer that they would carry out a closer inspection of the system once the vessel was clear of Dover. Despite the electrical stand-by pump cutting in during departure, the engineers noted that both ahead and astern pitch were seen to operate from the gauges on the control panel.

Departure Dover is normally achieved by using ahead demands on the CPPs. Astern demands are only required during manoeuvring when taking any necessary avoiding action, or correcting a navigational error, or during strong winds. As none of these events took place when manoeuvring on departure Dover, no astern movements were demanded.

After full away on passage, the chief engineer, second engineer and third engineer discussed what the next course of action should be. They decided to do nothing until the plans for the system had been examined in detail. Having had this discussion, the chief engineer left the ECR. This was normal.

The second engineer went up to the ship's office to obtain the schematic and physical plans for the CPP system. Although the plans he found were in English, the manual for the system was in Flemish.

During the crossing it had been decided to monitor the system and its hydraulic pressures closely. The positions for both CPPs were recorded in the engine room logbook. The logbook records that the setting for the port CPP from the OD box was 30mm, which is equivalent to 85%, and matched that of the starboard.

While examining the plans, the third engineer identified PSV3 as being the valve he had adjusted on the previous passage from Calais to Dover. The second engineer immediately recalled that when P&O Stena Line had first chartered the vessel, a problem had been experienced with the starboard CPP in which the pitch was unable to be changed. On that occasion, the control valve PSV1 was found to be faulty. Because of this problem, spare control valves were carried on board. The second engineer was aware of this, and prepared to use the spare to replace faulty valves on the port CPP system if necessary.

In readiness for the stand-by for arrival at Calais, the chief engineer went on duty in the engine room earlier than normal because he wanted to reassure himself that the port CPP system was operating satisfactorily. The second engineer reported to the chief engineer that everything had been in order with the system during the passage from Dover, with the pressures being normal. After discussing the topic with the second engineer, the chief engineer went to the gearbox room to make his own visual inspection of both CPP systems. He found the CPP system pressures to be normal at about 7 to 8bar for the control pressure and 50 to 60bar on the delivery side of the shaft-driven pumps.

Shortly after the chief engineer returned to the ECR, the bridge rang stand-by and informed the engineer that, as *P&OSL Canterbury* was to leave the port before *P&OSL Aquitaine* could enter, *P&OSL Aquitaine* would have to slow down earlier than usual. As the speed reduced, the engineers were unaware of any problem with the port CPP system. The engineers anticipated that if the electrical stand-by pump was going to cut in again, the most likely time would be when the bridge selected the constant rpm setting for the main engines, which enabled the bow thrusters to be run from shaft-driven alternators. This was because on the change to constant rpm there is a prefixed drop in the rpm and a slight reduction in the pitch. Alternatively, the electrical stand-by pump may cut in during manoeuvring from ahead to astern pitch when the main fluctuations in delivery pressure occur.

Meanwhile, the second engineer suggested, if the port CPP stand-by pump cut in again when entering Calais, they should check the system control valves, and in particular PSV1, which controls the oil pressure to the CPP actuator to obtain the desired pitch setting. Because of the delay in entering harbour, the chief engineer thought, although there would be sufficient time to check the valve, there would be insufficient time to carry out any remedial work if found necessary. It was decided if anything needed to be done to the valve it would be carried out in Dover after the next crossing.

Sometime after being told to slow down for *Canterbury,* those in the ECR felt the vessel vibrating. They also noticed that the propeller pitch indicators on the ECR console showed the port propeller pitch at 7.0 ahead, whereas the starboard pitch indicator showed 7.0 astern. They saw that both bow thrusters were operating hard to port, but had no idea what this manoeuvre was for. They thought it was associated with having to slow down for *P&OSL Canterbury*.

A couple of minutes or so later, there was a heavy jolt and everyone in the ECR was thrown forward. The two main diesel generators that were running stopped, and main electrical power supply was lost. *P&OSL Aquitaine* had hit the berth while still moving ahead at 7 knots. Before the stand-by generator had time to cut in, and within about 20 seconds, the engineers had restarted the two diesel generators and restored the main electrical supply.

The impact caused the port main engines and bow thrusters to stop. The starboard main engines continued to run.

The watchkeeping engineers searched the machinery spaces for possible flooding. None was found. Meanwhile the electrical circuit breakers were reset and essential auxiliary machinery restarted.

1.3.4 <u>Events on the bridge</u>

The master went on to the bridge about ten minutes before *P&OSL Aquitaine* arrived at the CA6 buoy in the approaches to Calais. The vessel was at full speed of about 20 knots with the stabilisers out. The master had decided to leave them out during the crossing because horses were being carried. Stand-by was rung at 0918 and the stabilisers were retracted.

At 0919, approximately 20 minutes before the impact with the berth, *P&OSL Aquitaine* passed south of the CA6 buoy, at a distance of two cables. She was in hand steering. The OOW reported by VHF to the port control, who confirmed the scheduled berth to be No 7. The port control also advised that *SeaFrance Renoir* was ahead and would berth first, but only after an outbound ferry, *P&OSL Canterbury*, had cleared the harbour. No further communication was made with port control until after the accident. The master could see *SeaFrance Renoir* ahead and decided to slow down to ensure a safe position in which to pass *P&OSL Canterbury*. At 0922, constant rpm mode on the main engines was selected.

SeaFrance Renoir then contacted *P&OSL Canterbury*, and both agreed to pass “green to green”. (The vessels would pass on each other’s starboard sides, meaning the vessels should stay over to their respective port sides of the channel). *P&OSL Aquitaine* contacted *P&OSL Canterbury* and allowed her master to choose how he wished to pass. Again, *P&OSL Canterbury*’s master chose to pass “green to green”.

When *P&OSL Aquitaine* was about halfway between CA6 and CA8 buoys, *P&OSL Canterbury* cleared the piers. At this point, the master took the “con” and manoeuvred the vessel more to the north of the channel to facilitate the “green to green” passing. He also increased speed temporarily.

At 8 minutes before impact *P&OSL Canterbury* was passed in the vicinity of CA8 buoy. The master then reduced speed by pulling back both combinators on the centre console. As the flood tide was running, which could be expected to push the vessel to the east, he ordered the helmsman to steer to the right of centre between the piers. As the vessel made its final approach towards the piers, the flood tide was not setting her as much as the master had expected. He reduced the allowance for the set accordingly.

Both bow thrusters were started at 6 minutes 14 seconds (forward) and 6 minutes 22 seconds (aft) before impact.

The seaman, who was acting as lookout, operated the control panel for the car deck doors, unlocked them, and then left the bridge to go to stations.

At 3 minutes before impact the vessel passed between the piers. The master estimated the speed to be about 12 knots. VTS recorded the speed to be 13.4 knots.

The required pitch indicated on both combinators was reduced to about 40%. At about this time he moved from the centre console, to starboard bridge wing console, to control speed and steering. After passing between the piers he reduced the pitch again.

At about 2 minutes before impact, and halfway between the piers and the Quai de Maree, the master realised he was still moving faster than expected and put both pitch combinator levers to astern. This would normally be more than sufficient to slow the ship significantly.

P&OSL Aquitaine then took a sudden sheer to starboard and towards *P&OSL Kent*, which was loading passengers and cars at No 6 berth; No 8 berth was unoccupied. To avoid colliding with *P&OSL Kent*, the master re-engaged the starboard rudder by setting the starboard CPP to ahead pitch, and setting the bow thrusters to thrust to port.

The bow started to swing to port. Starboard helm was applied, to prevent the stern swinging towards *P&OSL Kent* on the assumption that the starboard CPP was running ahead. As the vessel was then heading for the knuckle between No 6 and No 7 berths, thrusters were used to move the bow away from it.

P&OSL Aquitaine was now lined up for No 7 berth but still proceeding too fast. Full astern pitch was set on both combinators, whereupon the vessel took a sheer to starboard. The master attempted to parallel the berth by using the bow thrusters to hold the bow off the quay.

The passengers, meanwhile, were preparing to disembark. Although they had not yet been called to return to their vehicles, a few had made their own way down on to the car deck. Many people who used ferries frequently knew that the doors to the car deck would be opened locally, in advance of an announcement being made. The lifts, which operated throughout the voyage, descended to the lobby in front of the doors. Because it was possible to open the door, passengers had ready access to the car decks before they were permitted to do so.

Others were still in the public areas standing with their baggage by the access stairways to the car decks, awaiting instructions. Most passengers were standing up ready to disembark; some carrying bags, suitcases and/or cases of beer.

About 30 seconds before impact, the master realised the vessel was not going to stop in time, and collision with the quay was inevitable. The mooring party was ordered to clear the fo'c'sle, but no warning announcement was made to passengers.

The vessel struck the port (north) pad of No 7 berth. The time of the impact taken from the VTS radar recording was 09.39.05 seconds BST. Many people were thrown forward, falling on each other and hitting bulkheads and fixtures. Some passengers were thrown down stairways. Bottles, plates and glasses were smashed. Because passengers were unaware of what had happened, some confusion resulted. This was exacerbated by the loss of lighting in the passenger areas due to the electrical power failure.

The vessel's bow moved away from the quay and the port anchor was dropped. Lines were sent ashore from aft, and tug assistance was requested. The crew, assisted by passengers, began tending the injured until the shore paramedics arrived.

A tug arrived at 0956 and pushed *P&OSL Aquitaine* alongside some 10m off the linkspan.

After several hours, the vessel was turned around by tugs, and moored stern to the berth to allow the cars to disembark. Some passengers had to remain on board for up to 9 hours after the accident, waiting for vehicles to disembark.

1.3.5 Emergency action taken by crew

The vessel's emergency plan was activated immediately following the impact. One of the first actions carried out by the master was to inform the Calais police casualty department of the situation. In addition, the purser broadcast a prearranged message asking for any doctors among the passengers to assist. A doctor, one of the passengers on board, made his way to the information centre where, with the purser, he set about organising the casualties' treatment. Nurses among the passengers also volunteered to help. The information centre became the casualty reception, and a nurse took on the task of assessing the severity of the casualties' injuries to identify those in greatest need. French paramedics boarded the vessel at 0958 to assist the injured, and the French emergency services set up casualty treatment units on the quayside.

About 15 minutes after the impact, the master made his first announcement, informing the passengers that the vessel had hit the quay and that he would speak to them again when more information was available. Following this announcement, the master made three further announcements and the chief officer one. One of these asked the passengers to co-operate with the crew, and for those who did not require medical attention to remain seated. The other announcements concerned information about actions that had been taken and intentions for disembarking passengers and vehicles. About one hour after the impact, the information centre asked for all injured passengers to make their way to the casualty reception.

Those of the injured who could be moved were brought for treatment to the lounges near the information centre. Others were treated where they lay. Uninjured passengers were asked to make their way to the lounges on Deck 8 where they were asked to remain seated. The more seriously injured casualties were disembarked on stretchers and taken to hospital by ambulance. The last casualty was evacuated to hospital at 1235.

The purser toured the vessel to ensure that all injured passengers were receiving treatment and answered, as best he could, the passengers' questions. His staff reassured them, and maintained calm and order. He then briefed the master on the situation and the passengers' concerns.

1.3.6 Passenger injuries

A total of 180 passengers and 29 crew were injured as a result of the accident. The majority of the injuries sustained by passengers were bruising, sprains and whiplash. Five people had fractured bones. Several received blows to the head rendering them unconscious. About 58 people were treated in hospital and seven were detained for at least one night. Many more were treated on board or in the emergency medical facilities on the dockside.

The injuries occurred because people were thrown off their feet by the impact. Some were slammed into bulkheads. Others landed heavily on the deck 2 or 3m from where they had been standing. Some were caught under a crush of people falling on top of them. The most serious injuries appear to have occurred to those who were facing aft at the time of the impact, and who were thrown backwards (towards the bow of the ship) when the forward motion stopped abruptly.

Three of the injured were on a vehicle deck when the accident occurred. One had his legs trapped between two vehicles as a car lurched forward with the impact. Two others were thrown backwards off their feet, knocking their heads on the steel deck, and falling unconscious.

1.4 DESCRIPTION OF THE CPP SYSTEM (See Figure 2)

1.4.1 Manufacturer's CPP Maintenance and Operation Manual

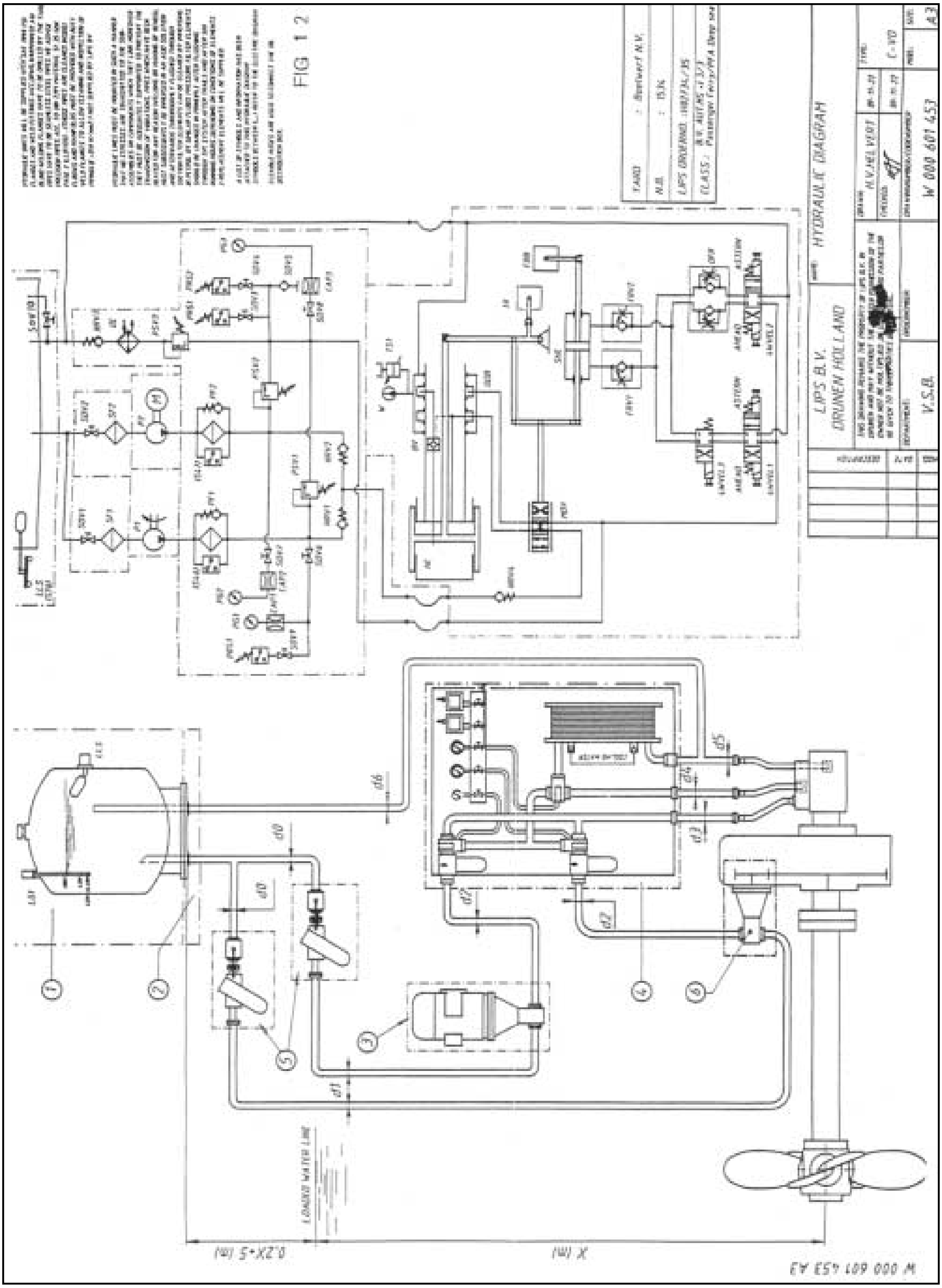
The *CPP Maintenance and Operation Manual* was on board *P&OSL Aquitaine* at the time of the accident and although the system drawings were in English, the manual was written in Flemish; a language not understood by the engineers.

The manual included a general description of the hydraulic system, complemented by system diagrams instructing individual component functions. The diagrams were sufficiently detailed to facilitate the tracing of system faults in the CPP hydraulic system. Although the written information was in Flemish, nowhere in the manual was there a fault diagnosis chart. The engineers were working from the CPP system diagram to resolve the problem **(Figure 2)**. The CPP control system on *P&OSL Aquitaine* was similar to that on *European Pathway* and, except for the chief engineer, the engineers on board *P&OSL Aquitaine* had served on *European Pathway* previously.

1.4.2 The CPP system

P&OSL Aquitaine is powered by four Sulzer 8ZAL40S diesel engines, driving two LIPS controllable pitch propellers. The diesel engines are in two sets: port and starboard. Each set leads to a single gearbox with a single shaft from the gearbox to one of the controllable pitch propellers. Each CPP has a dedicated hydraulic control oil system. Oil pressure in each system is maintained by one of two Abex Denison vane-type displacement pumps: an electrically-driven stand-by

Figure 2



CPP Hydraulic Control System

pump (P2) or main engine shaft-driven pump (P1). The entire CPP system was supplied and fitted when the vessel was built by LIPS, who are one of the world's foremost suppliers of such equipment.

The hydraulic system has two pressure ranges. The high pressure, which operates at approximately 45 to 98bar depending on demand, is used to operate the propeller pitch. The return oil from this system is regulated at approximately 8.5bar and is used for the control system, including servo operation and control of the stand-by pumps and low-pressure alarms. Under normal circumstances, the system is fully automatic. In port, the stand-by pump runs and supplies the system until the main engines are started and the clutches engaged, when the shaft-driven pump takes over and the stand-by unit shuts down.

The electrical stand-by pump will cut in automatically if there is a drop in pressure from the shaft-driven pump. When there is no, or insufficient, pressure to move the blades, they are hydraulically locked in the last achieved position. This is achieved by the blocking valve in C1 (ahead) line.

Referring to Figure 2 the header tank supplies oil through suction filters, (SF1 and SF2) to the pumps. The pumps discharge the oil at approximately 50bar through high-pressure filters (PF1 and PF2) and a non-return valve to the valve block on the oil supply unit. A pressure relief valve is set to lift at 98bar.

The oil is fed through a non-return valve (NRV4) and the follow-on slide (MDV) in the valve block and on to the propeller blade actuating piston.

The follow-on slide is equipped with a bottom piece, which maintains the pressure level in the system to a minimum level required to retain the pitch.

The oil flow returns from the propeller actuating piston to the follow-on slide's bottom piece, and on through the back pressure valve (PSV3), the oil cooler (OC) and a non-return valve (NRV3) back to the header tank. The oil return pressure from the slide-on slide valve is controlled by the back pressure valve (PSV3).

The non-return valves NRV3 and BV prevent unwanted and sudden reduction of the pitch as a result of an oil pressure loss.

The servo cylinder control (SHC), installed in the oil supply unit, is actuated by the oil back pressure, which in turn enables high pressure oil flow to the propeller actuators. Ahead or astern propeller pitch is normally achieved by operating electrically-controlled three-position four-way valves, 4WVEL-I and 4WVELI-3. Operation of valve 4WVEL-2 enables emergency control.

If the back pressure drops below a certain value, the first pressure switch (PRS1) will switch the hydraulic pump from main pump to stand-by pump.

Should the back pressure drop even further, the second pressure switch (PRS2) will activate the low pressure alarm.

The electrical stand-by pump starts and stops under the following conditions:

- With main engines stopped with zero pressure in the system, the pump has to be started manually. The pump will shut down automatically on high back pressure with no audible alarm.

- With main engines running, and the pump starter set on stand-by, the pump will start automatically in response to a set back pressure. An audible alarm will then sound, supplemented by illumination of the warning light on the ECR console. The pump must be stopped manually, and the starter must be reset again on stand-by mode to enable automatic restarting.

- When the main engines are started before departure, a pump logic card monitors shaft speed, and when a pre-set speed is achieved at which the shaft-driven pump will be providing sufficient pressure for the system, the electrical pump is stopped automatically.

Each of *P&OSL Aquitaine*'s twin rudders will centralise when its corresponding CPP is set to astern pitch. Control of rudder movement is regained by reverting to ahead pitch.

1.4.3 Control modes of main engine operation

There are three modes of operation, each with a different configuration of pitch/rpm.

1. Deep water mode - for full away condition with maximum main engine rpm. This mode is employed once the vessel is full away on passage, and enables maximum main engine rpm.

2. Shallow water mode - for use in shallow water conditions. Normally this mode is used when starting up and shutting down the propulsion plant. It provides the lowest main engine rpm.

3. Constant rpm - for manoeuvring with bow thrusters available. This mode is used invariably for stand-by manoeuvring, such as when arriving and leaving port. The load on each propeller shaft is limited to a maximum 66% full load available in deepwater mode.

Constant rpm mode is the only mode in which the bow thrusters can operate. The power take off (PTO) generators supply power to the bow thrusters; port and starboard PTOs to the aft and forward bow thrusters respectively

1.4.4 Electrical generator and bow thrusters

There are four 1430kW ABC diesel generators. Two are in operation at any one time, with an additional unit on stand-by which will cut in automatically if required.

The vessel also has two 1512kW bow thrusters. It is possible to run one thruster at a time. When both thrusters are running they operate together, but not as independent units.

1.5 POST-ACCIDENT INSPECTION OF THE PORT CPP SYSTEM

Shortly after the accident, the ship's engineers tested the pitch control using the stand-by pump with engines stopped. Pitch control was tested from the three bridge combinator controls, and from the combinator control in the ECR. Each control operated correctly.

The system filters were found to be clean. On running up the port main engines, the engine-driven pump discharge pressure was low at approximately 30bar. The non-return valves NRV l and NRV 2 were in good order. The relief valve for the engine-driven pump PSVI was changed for a new spare.

After the accident and, when the vessel was being turned around at the berth to enable discharge of vehicles remaining on board, the CPP system was tested with the main engines running. On starting the engines, the port engine-driven pump pressure was still at approximately 30bar.

With the port main engine still running, the port stand-by pump was switched to 'run' to ensure that the hydraulic system was properly primed. After about 5 minutes running, the engine-driven pump began to overheat. The port engines were stopped to avoid possible damage to the pump.

The pump and gear drive were removed, and the gearbox and pipework blanked. Port pitch control was again tested from each station using the port stand-by pump. The system operated normally as before. The vessel then sailed to Dunkirk with the port stand-by pump running continuously. During the voyage, the main engines and the port and starboard propellers operated normally without accident.

1.5.1 <u>Examination of the port gear-driven oil pump</u>

When the pump was stripped down, a fracture was found in two vanes extending to almost the full diameter of the pump rotor. Smaller fractures emanated from each vane slot. Scuffing damage found on one of the end plates was presumed to have been caused by the fracture. Despite the fractures, the rotor was still held in place on its driving splines which had only minor damage. There was evidence that the driving coupling had been heated, possibly when an oxyacetylene gas torch was used to assist fitting of the coupling when it was installed or overhauled. Suction and discharge filters were clean, without any sign of debris.

The stand-by pump cut in and alarm pressure switches, PRS1 & PRS2 respectively were tested. The results satisfied operating requirements which were:

- Pump cut-in 6bar (PRS1)
- Pump cut-out 7bar (signal from engine revolutions)
- Low pressure alarm 4bar (PRS2)

The stand-by pump logic card was tested using external inputs, and found to be fully functional. Associated electrical control systems did not reveal any faults. The LIPS service engineer applied a creep test to both propellers. Both started to move at 20bar. The system in general was checked and the non-return valves NRV1 and 2 re-examined. The tests and checks confirmed the CPP hydraulic oil system to be in good condition.

1.6 SUMMARY OF CPP PRINT-OUT OF RECORDS OF VOYAGE FROM DOVER TO CALAIS

1.6.1 Leaving Dover

08.17 As the vessel left her berth in Dover with CPP system on constant rpm mode, demanded and achieved pitch seems to have been coincident on both port and starboard propeller.

08.24.57 Deep water mode selected. Port and starboard CPPs at 140 rpm.

08.25.09 70% achieved pitch on port propeller.

08.25.14 90% demanded pitch on port propeller, no indication of port propeller pitch change from 70% as recorder stopped at 08.25.30 (but see entry for 09.26.28 below).

08.25.30 80% achieved pitch on starboard propeller.

1.6.2 Approaching Calais

Demand and achieved port and starboard propeller pitch are described in graphical form in **(Figure 3)**.

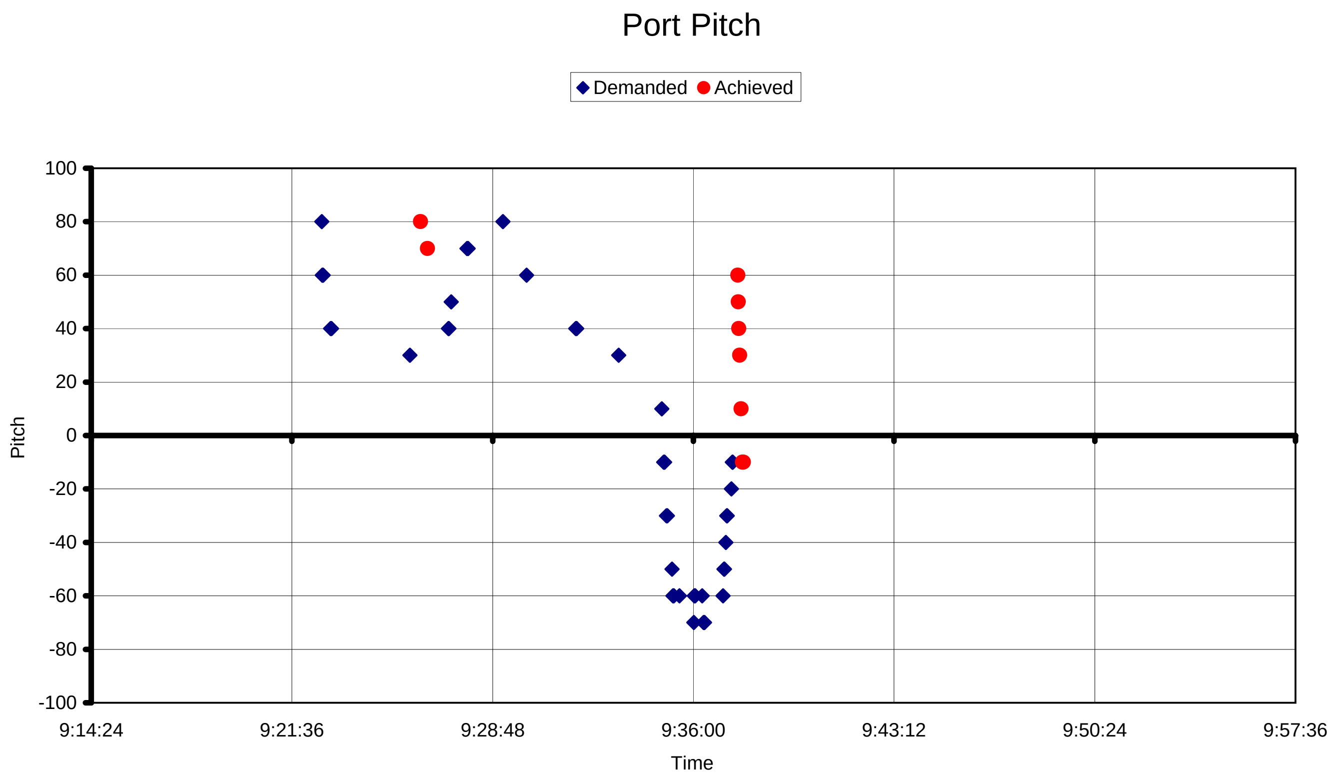
The starboard CPP operated normally, but the port did not respond.

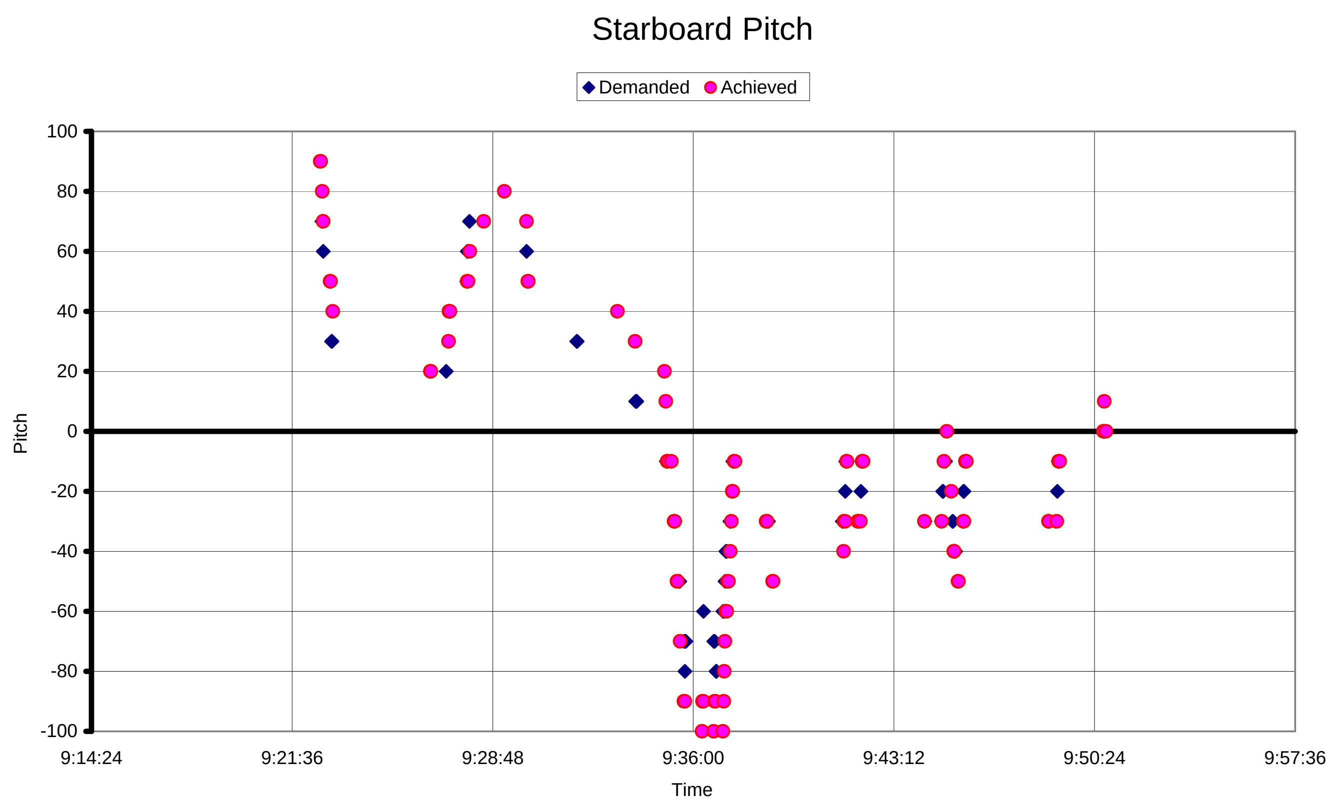
09.22.50 CPP system on constant rpm mode.

09.25.50 30% port propeller pitch demanded.

09.26.28 Port propeller achieved pitch change from 80% to 70%.

From this time on there was no recorded response to port propeller pitch demands.


Port Pitch
Demanded
Achieved
Pitch
100
80
60
40
20
0
-20
-40
-60
-80
-100
9:14:24
9:21:36
9:28:48
9:36:00
9:43:12
9:50:24
9:57:36
Time


Starboard Pitch
Demanded
Achieved
Pitch
100
80
60
40
20
0
-20
-40
-60
-80
-100
9:14:24
9:21:36
9:28:48
9:36:00
9:43:12
9:50:24
9:57:36
Time

1.7 SPEED IN HARBOUR AND AT IMPACT

The Calais VTS radar picture was used to establish the vessel's speed on entering the harbour. The radar echo was used to determine time and distance and, therefore, speed. The radar vector could not be relied upon because it was roaming around the echo of *Aquitaine* and also the quay. The radar picture showed that the vessel's bow entered the breakwater at 09.35.40 BST, passed the knuckle between No 6 and No 7 berth at 09.38.05 and impacted with No 7 berth at 09.39.05. The distance covered and subsequent speed is shown below:

	Time	Distance	Speed
Breakwater to knuckle No 6/7 berth	145 seconds	890 metres	11.93 knots
Breakwater to impact with No 7 berth	205 seconds	1090 metres	10.34 knots
Knuckle to impact	60 seconds	220 metres	7.13 knots

The table shows that the average speed over the last minute before impact was 7.13 knots. As the radar picture shows the motion to be reasonably constant over this minute, it can be concluded that the speed on impact was around 7.0 knots.

1.8 SUMMARY OF REASONS WHY THE PORT CPP FAILED TO RESPOND TO PITCH CHANGE DEMANDS

Because of the damaged rotor vanes of the port shaft-driven pump, the pump was unable to deliver enough pressure to enable a port propeller pitch change on demand by movement of the combinator lever.

LIPS estimated that at least 35bar pressure was needed to move blades. Post-accident tests showed that the pump could generate only 30bar.

However, the pressure generated was sufficient to maintain normal pressure on the low side of the system (the back pressure referred to earlier in the section). Pressure switches PRS1 and PRS2, activated by the low pressure side of the system, were tested and found to be set and operating at the approved trip pressures.

The alarm print-out records indicate that neither switches activated, on the vessel's approach into Calais harbour and No 7 jetty. It was concluded that when the vessel was approaching Calais harbour the pressure did not drop sufficiently to activate them. At the same time, the high pressure side was too low to enable pitch changes. When high pressure was lost the system functioned as designed; the blades locked in the last achieved setting.

The CPP instruction manual indicates a pressure switch, PRS3, fitted to the high pressure side of the system. During building of the vessel, LIPS did not connect this switch. LIPS stated that the original design function of PRS3 was to stop the stand-by pump when there was enough pressure in the pressure line of the shaft-driven pump. But after experience on other ship installations, they decided to change the stopping function of the stand-by electric pump by a signal from shaft revolutions.

1.9 DAMAGE TO SHIP'S STRUCTURE AND VEHICLES (See Figure 4)

The vessel sustained damage to her bulbous bow, forward upper and lower fixed fenders, fore peak and forward clam door. About 200 vehicles on the car decks were damaged. There was also damage to various fittings, furniture and crockery. The vessel received temporary repairs in Dunkirk. Repairs were completed in Falmouth. She resumed full service in early June 2000. Calais No 7 berth was badly damaged and was out of use for several months.

Figure 4

Damage to bow

1.10 ENVIRONMENTAL CONDITIONS

The weather was good at the time of the accident with a light south-westerly wind. The last hour of the flood tide was running, which gave an easterly set in the channel. The visibility was good.

1.11 CREW

All officers on *P&OSL Aquitaine* were British. The masters work a 12 hours on 12 hours off shift system. After one week they go on leave for a week, then they return to the vessel.

The master on board at the time of the accident was 55 years old, and had been at sea for 39 years. He obtained his master's certificate in 1972. While serving as a senior chief officer in 1993, he gained a Port of Calais pilot exemption certificate (PEC) in July of that year. The PEC allowed him to sail as relief master on an opportunity basis, although few opportunities arose between 1993 and 1998. He was promoted to relief master in September 1998 and to master in August 1999, although he was not finally substantiated as a master until November 1999. Between September 1998 and November 1999 he sailed as relief master on *European Seaway*. In addition, he also sailed as relief master on *P&OSL Calais*. On being substantiated as a master in November 1999, he joined *P&OSL Kent*. Before taking command on 28 February 2000, he had completed a 10-day familiarisation period. Since his previous appointment as master, he had had three weeks actual experience in command of *P&OSL Aquitaine*.

The 53 year old chief engineer had been at sea for 28 years. He obtained his class one engineer's certificate in 1981. After four years as relief, he was promoted to permanent chief engineer in 1991. He had been chief engineer on *P&OSL Aquitaine* since November 1999.

The 48 year old first officer had been at sea for 32 years, and had served in this capacity on *P&OSL Aquitaine* since she came into service with P&OSL.

The second engineer was 38 years old. He had been at sea for 18 years, and had been second engineer on *P&OSL Aquitaine* since she came into service with P&OSL.

1.12 MANNING AND CERTIFICATION

The certification issued in respect of *P&OSL Aquitaine* was valid, and she was manned in accordance with her safe manning certificate. The master had a valid Calais pilot exemption certificate (PEC), which exempted *P&OSL Aquitaine* from the requirement to use a Calais pilot. The vessel had been issued with an International Safety Management (ISM) certificate.

1.13 SHIP ROUTINES

1.13.1 Bridge routines

The master normally goes on to the bridge about 15 minutes before sailing. The duty officer completes a pre-departure checklist. The master will seek confirmation that the required checks have been completed before signing it.

Before the master can inform port control that the vessel is ready to sail, company regulations require that the three heads of department, the chief engineer, chief purser and chief mate, and the officer-in-charge on deck, report verbally to the master that the vessel is ready to proceed to sea. The chief engineer's report includes the state of machinery. Once these reports are received, the controls for operating the shell doors and platform decks are electrically isolated. The passengers are informed that the vessel is ready and about to proceed to sea. Meanwhile, port control is advised that the vessel is ready to leave. The port control, in turn, informs the master about other vessel movements.

The master, bridge officer, quartermaster and a second quartermaster are on the bridge for arrival and departure. A further set of post-departure checks are made and recorded at the foot of the main departure checklist.

Once the vessel is clear of the port and the master is satisfied that the immediate traffic situation and visibility are not causing concern, navigation will be handed over to the OOW for the duration of the crossing. If, however, there is any cause for concern, the master may stay on the bridge throughout the passage. When the OOW is satisfied with the traffic situation, auto-steering is engaged. One quartermaster always remains available on the bridge to take over hand-steering while the other acts as lookout.

The speed during the crossing is normally about 20 knots. When the master is not on the bridge he will have a portable VHF radio with him so that he is available should the OOW require him. Normally the master is advised of stand-by 10 minutes before it is ordered. On arrival at Calais, this means he will be expected on the bridge before the CA6 buoy is passed.

The charts for the Dover - Calais area are kept under a Perspex cover. Manual plotting of positions is made directly on to the Perspex rather than on to the chart itself. A raster ECS was fitted for a trial period, but was not normally used for position fixing.

Just before arrival at the berth an announcement is made, informing the passengers that they may return to their cars. At the same time the master instructs the quartermaster to operate the car deck doors' control panel. This panel has three settings: locked, unlocked and open.

1.13.2 Engine room routines

During stand-by for arrival or departure the chief engineer, two engineer officers and a motorman are on duty in the engine room. The second engineer (a dayworker), will sometimes be present in the control room. If the electrical officer is not already in the control room, he is on call for engine room duty when necessary.

During the crossing and, if running one engine in port, there will always be an engineer officer in the control room. If an alarm sounds there are audible and visual warnings in all spaces.

Before leaving port, the bridge normally gives the engine room 15 minutes and 5 minutes notice to start the main engines. By then the chief engineer is normally on duty in the engine room. An engine room departure checklist is completed before the chief engineer advises the master that the propulsion plant is ready for the vessel to go to sea. Once the main-engines are started, constant rpm mode is selected and control is transferred to the bridge.

After full away on passage (FAOP) the bridge will request the deep water mode of engine operation. In readiness for arrival into port, the chief engineer is normally on duty in the engine room.

1.14 THE PORT OF CALAIS (See Figure 1)

Calais is the most important cross-channel ferry terminal on the French side of the Dover Strait. It also handles a considerable number of commercial vessels and cargo. During the summer months there are about 100 ferry movements each day.

The approach channel to Calais parallels the shoreline for about 4 miles from the west, before turning inland between two breakwaters. The two breakwaters are Jetee Est and Jetee Ouest which are converging piers 230m apart at the port entrance. The approach channel is buoyed on the northern side with the buoys being the following distances from Jetee Est:

CA6 3.05 miles west

CA 8 1.1 miles west

CA 10 0.4 miles NW.

The protected channel between the piers forms Avant port which extends 4 cables NW from the coast.

Berths 5, 6, 7 and 8 are mainly used by P&O Stena Line, and lie on the SE side of Avant port. Berth 7 lies to the west of berth 8 and east of berths 5 and 6. It is the longest of the 4 berths. It consists of a linkspan and concrete apron with rubber pads and fendering.

A VTS scheme with radar surveillance is in operation and based on the end of the Quay de Marie. Inbound cross-channel ferries report on passing CA6 light buoy. Pilotage is compulsory for all vessels over 50m in length. Almost all the cross-channel ferry masters possess a PEC based on experience of regular users of the port. The master's PEC number is reported to port control when passing CA6 buoy.

The harbour regulations within Avant port restrict speed to a maximum of 10 knots.

1.15 VOYAGE DATA RECORDER

Although there is, at present, no legal requirement to do so, vessels in the P&O Stena Line Group have been fitted, at great expense, with voyage event recorders, often referred to as voyage data recorders (VDRs). They have been provided for a variety of purposes, including the provision of accurate data in the event of an accident. Such information is of great assistance in the reconstruction of the circumstances surrounding an accident and also, possibly, in understanding why events have taken place.

Following the accident, the VDR tape was removed from the vessel. It transpired, however, that at the time of the accident, the VDR had malfunctioned and had not, therefore, recorded the events. It was therefore of no assistance in the investigation. The unit was found to be in alarm mode, as indicated by an LED light signal on the front of the VDR casing.

The VDR was fitted in the radio room, which was next to, but separated from, the bridge. Although the VDR was out of sight of the routine bridge activities, fleet regulations require that during service all navigational and bridge equipment, which includes the VDR, shall be tested every 24 hours. The last time a check of the equipment (including the VDR) was carried out, was on the morning of the accident, before the early morning Calais departure. Thus, in the time interval between the unit last being checked, and the accident, an undetected fault had arisen. In this instance, a defect on the VDR denied accident investigators useful evidence to assess what happened during the minutes leading up to, and immediately following, the accident.

It is the company's responsibility to see that it works at all times. Following the accident, P&O Stena Line fitted an alarm indicator light in the bridge.

1.16 INSTRUMENTATION

1.16.1 Bridge consoles **(See Figure 5)**

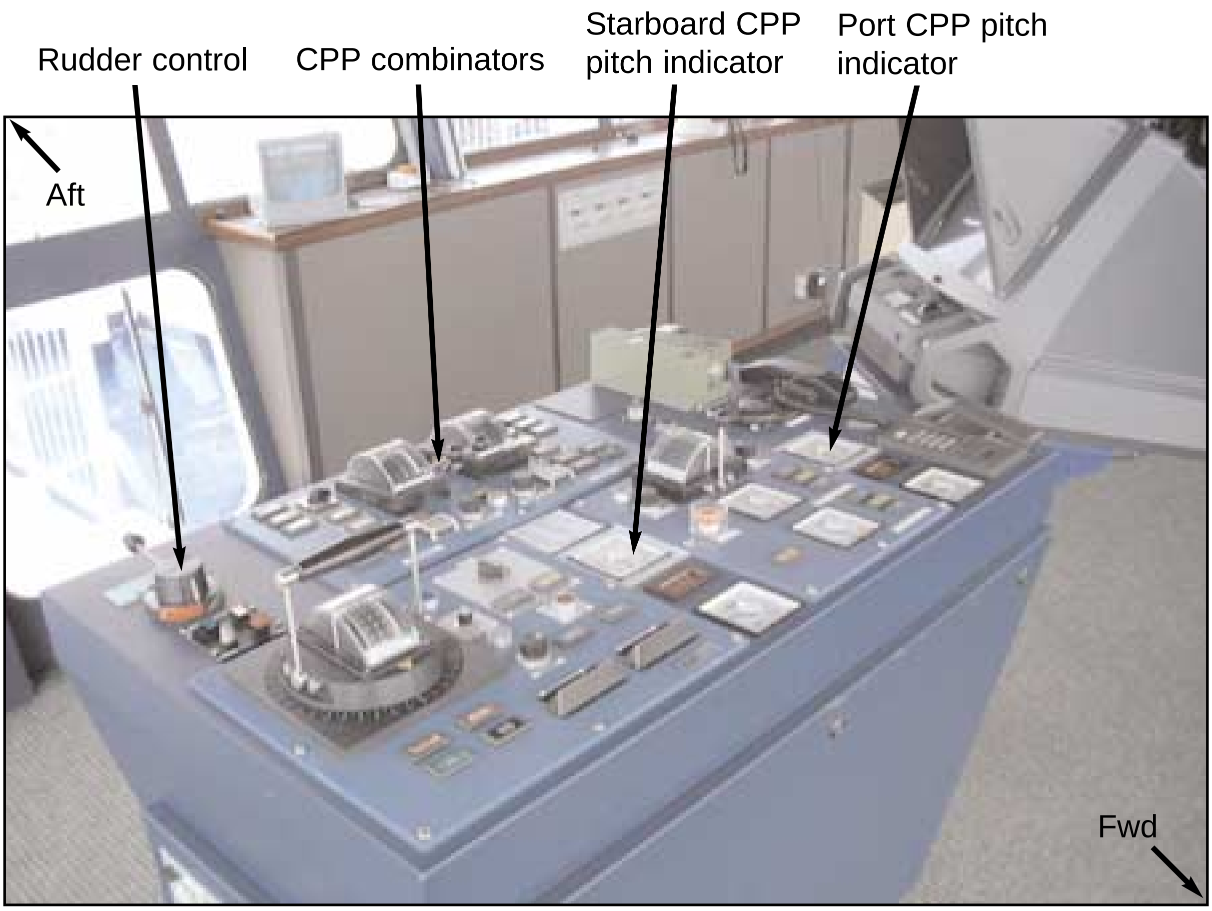
The bridge has “enclosed” wings which are an integral part of the bridge.

There are three sets of control consoles on the bridge. One is located centrally on the bridge, and the other two are on each of the bridge wings. The rudders and CPPs can be controlled from each console.

Immediately before berthing, the master will move to the bridge wing to control the vessel. Each console has port and starboard propeller pitch achieved indicators. All three consoles have main engine emergency stop buttons. On the starboard bridge wing, which was in use during the accident, the gauge for the starboard CPP is located immediately forward of the pitch control levers, the port gauge is offset to the left and on the far side (inboard) of the console.

Demanded propeller pitch is indicated on each of the CPP control levers located at each console.

Figure 5



Starboard bridge wing console

1.16.2 Bridge ergonomics

On the starboard bridge wing, which was in use during the accident, the pitch gauge for the starboard CPP is located immediately forward of the pitch control combinators. The port gauge is offset to the left and on the far side (inboard) of the console. During manoeuvring ahead, the master stands immediately behind the console in way of the pitch combinators. From this position he can see the bow and starboard side through the forward window Thus, each time he wanted to adjust the combinator settings he had to lean over the console. From the position where the master stands it is not possible see the port gauge unless he specifically looks to his left.

1.17 SYNCHRONISATION OF CLOCKS

Although the fleet regulations require all clocks on board *P&OSL Aquitaine*, including recording devices, to be synchronised to the time displayed by the (D) GPS system every 24 hours, the various clocks on *P&OSL Aquitaine*'s recording devices were found to have different synchronisations of up to 4 minutes. The Calais VTS time was used as the datum, and all the vessel times had to be synchronised by working back from the impact. The following table shows the differences in times given by the various recording devices for the moment of impact:

Recorder:	CPP log	Deck log	ER alarm print-out	Course recorder (approximate)	Calais VTS radar video
Time (BST)	09 37 36	09 35	09 36 38	0936	09 39 05

1.18 PROPELLER PITCH INDICATOR CALIBRATIONS

Annex 1 shows the propeller calibrations for both port and starboard propellers in constant rpm and deep water modes.

The calibration showed that the indication for demanded and achieved pitch in both constant rpm and deep water modes were correct.

1.19 BRIDGE TEAM MANAGEMENT RELATED REGULATIONS AND ADVICE

There was advice on board relating to the role of the master and officers when manoeuvring, which highlighted the importance of careful monitoring of helm orders.

P&OSL's fleet regulation, shipboard operations deck department section 20.1 states:

"The officer assisting the master, or the master if roles are reversed, shall closely monitor all helm orders to ensure that;

- *The orders are appropriate for the intent of the manoeuvre,*
- *They are correctly carried out."*

Senior master's standing orders section 4.12.2, Responsibilities of OOW During Harbour Manoeuvres, states:

"These include assisting the Master (monitoring orders passed; the correct acknowledgement & execution of helm & other orders; observing correct propeller pitch angle etc); checking operational readiness of radars, target selection & radar watchkeeping; and ensuring that correct VHF watch is maintained."

Every ship's officer is issued with the Nautical Institute publication *Bridge Team Management* and has to sign that it has been read. This publication states in chapter six entitled "*Teamwork*":

" the watch officer will monitor the execution of helm and engine orders......."

The ICS publication *Bridge Procedures Guide* states in Section 3.2.5.4 "Checking orders":

"Good practice also requires the OOW to check that orders are being correctly followed. Rudder angle and engine rpm indicators, for example, provide the OOW with an immediate check on whether helm and engine movement orders are being followed."

SECTION 2 - ANALYSIS

AIM

The purpose of the analysis is to determine the contributory causes and circumstances of the accident as a basis for making recommendations to prevent similar accidents occurring in the future.

2.1 INTRODUCTION

The record of propeller pitch achieved and demanded shows that the starboard propeller responded normally to bridge control throughout the crossing from Dover to Calais.

Although the record for departure Dover shows that the port propeller was only at 70% pitch when the recording was stopped, the record for arrival at Calais shows that the port propeller had attained 80% pitch which then reduced to 70%, but thereafter remained in this position until after the accident. The engine room logbook records that the pitch during the crossing from Dover to Calais was 30mm on the OD box for both propellers. This correlates to 9.5 on the pitch indicator, or about 85%.

The pitch on the port propeller dropped to zero when the port engines stopped as a result of the impact with the quay.

Unknown to the engine room and bridge teams, control of the port CPP had been lost while entering Calais. Although the exact time of the loss cannot be ascertained accurately, the last recorded movement of the port CPP was at 09.26.13, about 13 minutes before the impact, when the pitch reduced from 80% to 70%. Consequently, on *P&OSL Aquitaine*'s approach to the berth in Calais, her master did not have normal control of the vessel to enable a safe and uneventful docking.

2.2 FAILURE OF CPP SYSTEM

Port CPP control was lost because rotary vanes of the main shaft-driven pump were damaged. Despite the damage, the pump was able to maintain sufficient oil pressure and flow on the low-pressure side of the system to ensure that the stand-by electrical pump did not cut in.

However, the pump was unable to produce enough pressure in the high- pressure side of the system to cause the blade pitch to change in response to movement of the pitch control combinator lever.

Consequently, because the oil pressure in the high pressure side of the system had dropped below the minimum pressure required to move the blades, the blades locked in to the last pitch achieved position.

In post-accident tests, the LIPS service engineer found that the pump probably supplied enough pressure (35bar) to maintain a back-pressure (control pressure) of 8bar. The cut in pressure of the stand-by pump was below this value and was reported to be 6bar.

These pressures were within the normal operating range for the system. The safety feature to prevent loss of propulsion worked: when the high pressure dropped outside its operating range, blade pitch, and thus propulsion, was maintained.

However, the system guard, designed to prevent a drop in pressure outside the high pressure operating range, failed when the stand-by pump did not cut in on the vessel's approach to Calais. A consequence of this was loss of propulsion control.

2.3 LIMITATION OF ENGINE ROOM INSTRUMENTATION

On the previous crossing from Calais to Dover and during stand-by leaving Dover, the main shaft-driven pump delivery pressure dropped enough to start up the stand-by pump.

During the crossing from Dover to Calais the CPP system seemed to be performing normally. The engine room log recorded that the reading on the CPP oil distribution box (OD Box) indicated that both CPPs were set at the required pitch. The engineers were satisfied that system oil pressures were normal. Despite this normality, the engineers continued to be vigilant, concerned that they had not fully solved the problem.

During the approach to Calais, the loss of port main pump delivery pressure was insufficient to start up the stand-by pump.

The engineers had no obvious warning that the port engine-driven CPP pump delivery pressure was unstable and liable to fluctuation. The system was not designed to give this warning.

LIPS reported that they had considered only the possibility of complete loss of system pressure because of engine-driven pump failure. The possibility of this loss was meant to be avoided by the automatic start up of the stand-by pump to maintain system pressure.

The risk of partial loss of hydraulic pressure was not identified by LIPS.

Had pressure gauges for the CPP system been fitted in the ECR, it is possible the engineers would have detected the loss of pressure in the port system in sufficient time to warn the master so that he could take appropriate action.

Although there was an audible alarm to indicate low oil pressure on the low pressure side of the system, no alarm had been fitted on the high pressure side of the system. This would indicate a pressure lower than the minimum required to move the blades against normal hydrostatic pressures while the vessel was underway. Had there been such an alarm, the engineers would have been alerted to the fact that the port shaft-driven pump was not providing the required system pressure to change propeller pitch.

Monitoring the pressure was not a simple task. There was no oil pressure remote read-out facility, making it impossible to monitor it continuously from the ECR. Instead, the system pressure gauge had to be read locally, near to the oil supply unit situated in the gearbox room located aft. This was some way from the ECR, separated by four watertight doors. As the watertight doors are always closed during arrival and departure, for safety reasons, the need to open and close these doors to reach the gearbox room could result in it taking several minutes to get there. As a result, frequent checking of the gauges during manoeuvring was not normal practice. The pressures were, however, logged every 4 hours, the last check being carried out during the crossing from Dover to Calais, when normal expected pressures were noted.

There was no obvious indication in the engine room that propeller pitch changes were corresponding to that of bridge combinator movement. It can be checked by moving the engine room combinator to bring it in line with that on the bridge. At this point, a lamp illuminates to indicate the coincidence. This indication is designed to enable smooth changeover from engine to bridge control, and vice-versa. It is not intended to be used as an operational check of CPP system function.

2.4 DIAGNOSING THE FAULT WITH THE CPP SYSTEM

The engineers were first aware that something was wrong during the crossing preceding that of the accident. The chief engineer believed the reason for the stand-by pump cutting in with unusual frequency was possibly due to changing between ahead and astern pitch, when major fluctuations in pressure in the system occurs.

To find out what was wrong with the CPP system the engineers attempted to eliminate the obvious and simple possibilities, initially by trial and error. Given the limited turn round time in port, and the shortage of time to carry out complicated and time consuming diagnostic work, this was reasonable when problems with the CPP became evident.

Later, when leaving Dover, the chief engineer thought the pump might be cutting in due to air having been introduced into the system when the third engineer checked the suction filter in Dover. He expected this would eventually vent to atmosphere through the header tank. Had the main engine -driven pump discharge filters been opened up, the engineers might have discovered metal debris from the damaged pump. Had they done so, the finding would have led them to suspect the possibility of damage in the system which could have been the cause of the problem.

Although it later transpired that the chief engineer's thoughts about what could be the problem, were wrong, the engineers, nevertheless, continued to monitor the system closely during the crossing to Calais. Also as part of the continued fault-finding exercise, they examined the system drawings and discussed possibilities with the chief engineer.

The drawings, which were annotated in English, assisted the engineers in the fault-finding process. But the operation and maintenance manual, which should have been of help, was not. It was written in a language that none of the engineers understood. Although it had a section describing the general arrangement of the hydraulic system and function of system components, albeit written in Flemish, there was no fault-finding or trouble-shooting section.

This was an important omission. The third and second engineers' knowledge and experience of the LIPS system were important assets in their attempts to find out what was wrong. An operations and maintenance manual, carefully designed, easily understood and relevant to the needs of the engineers, would have helped their thinking, to solve the problem. There is no point in having an instruction manual if nobody can understand or use it.

When they took over the vessel 12 months earlier, the management should have made sure that the CPP system manual was in a usable form. It is important that the chief engineer is satisfied he has all information available to enable him to make a fair appraisal of the situation. He should not have to depend solely on the experience of his officers.

2.5 CHIEF ENGINEER'S REPORT TO THE MASTER BEFORE LEAVING PORT

The chief engineer satisfied company requirements by reporting directly to the master before leaving Dover, but because he thought it only a minor problem, he decided not to report his thoughts about the CPP system to the master. Had he done so, it is possible the master would have accepted the chief engineer's view that the cutting in of the stand-by pump would not affect the overall performance of the CPP system.

But having been told of the problem, the master might well have been more aware of the possibility that something could go wrong with the system. Had this been the case, it is possible that he would have briefed his bridge team before leaving Dover, and taken particular note of instrumentation on the bridge. As the vessel approached Calais, he might have noticed the warnings of inconsistent pitch readings and unusual vessel handling.

When approaching the harbour entrance, neither the master, nor the first officer, noticed that the port propeller pitch remained fixed at 70%, despite changes in demand. Given these conditions, manoeuvring within the harbour was bound to be precarious. Despite this, however, when dangerous situations arose with the vessel sheering towards *P&OSL Kent*, and subsequently towards the knuckle at the end of the No 7 berth, the master acquitted himself extremely well in successfully avoiding accidents which could have been greater than the vessel's impact with the berth.

During the last 11 minutes of the voyage, the port propeller pitch remained stationary despite the master altering the combinator setting to astern pitch. Only the starboard propeller pitch was brought down to zero and put astern. The port side remained at 70% ahead, but nobody noticed.

Had the master or the first officer observed and noted the port and starboard pitch indicator readings in those last few minutes, they would have realised that the master was manoeuvring using only the starboard propeller. Such a realisation, along with knowledge of previous problems with the stand-by pump, would have provided a timely warning that action was necessary to regain effective control of the vessel.

2.6 BRIDGE TEAM MANAGEMENT

Entering Calais

The role of the master is to have the conduct of the navigation and overall command. The role of the OOW is to be part of the bridge team supporting the master in a navigational role, which includes reporting deviations from the intended passage plan and monitoring execution of helm and engine orders.

According to the master, he preferred to navigate his vessel towards, or away from, a berth by feeling the combinators' control, rather than by reliance on observing the console pitch control indicators. For an experienced navigator, such a preference is an accepted and effective practice when concentration of effort needs to be high. Too much reliance on observation of the pitch gauges could be a burden on his workload and a distraction from safe navigation.

In the 15 minutes leading up to the accident there were pitch demands, almost 1 every 10 seconds. With all these movements, it was important that the bridge team was satisfied that the equipment responded to the master's intended actions. The OOW had a key role in verifying these actions, and was required to do so by the senior master's standing orders (section 1.9).

The port CPP pitch indicator was not checked at all by the master or the OOW. Had they observed the console instrumentation during the manoeuvre into the port, they would have realised that something was wrong with the controls.

The team must be assured of dependable combinator controls. At Dover, they were assured by the engineers that, as far as they were concerned, the vessel was fit to go to sea. However, this assurance was not a dispensation to avoid further checks by the bridge team that the machinery controls were operating to their satisfaction before, and while, entering port.

When the vessel initially slowed down at 0918, as she approached Calais, there was time to check that movements of the combinator controls coincided with movement of the pitch indicators. Such a check on this occasion might not, however, have revealed that the port CPP was not responding to combinator demands, since the shaft-driven pump for the port CPP system might well have failed after that time.

Had the master realised there was a problem with the port propeller pitch control, there is little doubt his actions would have been different. He would have had the option of entering the harbour on one engine and/or calling for a tug.

2.6.1 Action taken by the master

Once the master realised that his speed was excessive, he moved both combinators to the full astern position. However, with the port CPP stuck in 70% ahead, and the starboard CPP moving astern as demanded, this had the effect of slewing the bow to starboard. At 1 minute and 17 seconds before impact, the starboard CPP was at 100% astern pitch and the port engine at 70% ahead. This produced excessive vibration and a large slewing moment to starboard.

When the master realised the vessel was swinging to starboard towards *P&OSL Kent*, moored on berth No 6, he needed to stop the swing and move the bow to port. Thinking that he had both propellers astern, he believed that both rudders were fixed in neutral. As a result, he thought at least one propeller would now have to be placed on ahead pitch to regain steerage. Unknown to him and his team, the port rudder steerage was actually available because the port CPP was already set at 70% ahead.

The CPP log print-out shows that the starboard CPP decreased from 100% astern in the minute before impact, but never actually went ahead. The possibility that the indicator malfunctioned cannot be ruled out since, according to the engineers, the starboard CPP was 7.0 astern and the port CPP was 7.0 ahead, with the bow thrusters to port, at the time of impact.

However it is possible that the master:

- never put the starboard CPP combinator to ahead, or,
- did not leave it in the ahead position long enough for the demanded pitch to be achieved or recorded.

The master probably moved the rudder control to port, believing this would be moving the starboard rudder. In fact, it moved the port rudder. The use of the bow thrusters thrusting to port also helped in slewing the bow to port. If the pitch on the starboard CPP had been reduced to 10% astern, the vessel would also have increased speed slightly at that time since the port CPP was still locked at 70% ahead.

As *P&OSL Aquitaine*'s bow swung to port to avoid *Kent*, her stern began swinging to starboard. The movement was checked by using starboard helm, and the two vessels came within a few metres of colliding. *Kent* was embarking passengers at the time. Although it is impossible to gauge what might have happened had a collision occurred, it can be assumed there would have been substantial damage to, and injuries on board, both vessels. The possibility of some injuries being fatal cannot be discounted.

The master used the vessel's thrusters to avoid the knuckle at the end of berths 6 and 7, but had still not put the starboard combinator back to full astern. Had he done so, the effect of the impact with No 7 berth might have been less. Because there was only 1 minute to go before impact, there was little time to gain the full effect of moving the blades full astern.

Shortly after passing through the piers, the bridge team knew that the speed was excessive. As the combinators were being put astern, they were also aware that the vessel took a sheer to starboard towards *Kent*. It was thought that this sheer was caused by currents in the harbour. A further sheer when off the berth was put down to interaction between the bow and the quay. It was believed that going full astern on both engines would have been sufficient to stop the vessel. Only when she was half way into No 7 berth did the master realise that he was unable to stop the vessel in time to prevent contact. However, before impact, the last demanded pitch on both CPPs was 10% astern. It is not known if the master had, in fact, demanded full astern on both CPPs. It is possible he had, but there was insufficient time to register the pitch changes on the print-out.

The slewing of the vessel towards *P&OSL Kent* and, subsequently, the knuckle, were very serious situations and it is likely that the gravity of the moment absorbed the master's full attention, at the expense of other actions. During that time there was nothing of more importance to him than avoiding colliding with these objects. The circumstances made it difficult to manoeuvre, but the master succeeded in avoiding these collisions.

When the master realised *P&OSL Aquitaine* was going to strike the berth, there was no time to use the anchors. The master warned the fo'c'sle party to clear the bow, but gave no warning to the passengers.

2.7 NAVIGATION IN CALAIS HARBOUR

Calais port harbour regulations, article 9, restricts speed within Avant port to a maximum of 10 knots. *P&OSL Aquitaine* was exceeding this as she came through the piers, yet there was no communication between port control and the vessel until after the impact. It is believed that the port control was unaware that the vessel had a problem until after the impact with No 7 berth, when the master called to advise them of the accident. The master stated it was normal to pass through the piers at between 10 and 12 knots. This is in excess of the Calais port regulations speed requirement, which came into force in August 1996.

P&O Stena Line did not instruct its masters regarding this requirement until 20 June 2000; 54 days after the accident and almost 4 years after the speed restriction came into force. P&O Stena Line report that they were never advised of this regulation until June 2000.

2.8 PASSENGERS

Two aspects of this accident relate to the embarked passengers: the lack of a warning, and their handling afterwards.

2.8.1 Warning

A feature of this accident was the number of injuries to both passengers and crew. They were caused when, without warning, *P&OSL Aquitaine* hit the jetty and suddenly decelerated.

The master had time to compose and make an announcement to the fo'c'sle party before impact. This doubtless prevented injuries forward. It could be argued that the bow area carried the higher risk for injuries in this situation.

The only people in a position to give an appropriate warning were the officers on the bridge. Although they knew the speed was excessive as they shaped up for the berth, they had little inkling about what was likely to happen until relatively late in the manoeuvre. The evidence indicates this probably occurred some 30 seconds before impact. Because the vast majority of the 1241 passengers were already congregating to go to the car decks when given permission, it is impossible to make a judgment on the effect any such warning would have had with only seconds to go. However, the lack of any warning denied everyone the opportunity to do something to prevent injury.

It is very easy to criticise the bridge officers for not giving a warning. They were facing a very difficult situation, and the master's attention was fully occupied in the moments leading up to the impact. Even if such a scenario had been considered beforehand as part of a risk assessment analysis, it is possible that a sudden announcement to the passengers would have not prevented injuries. When such sudden announcements are made, there is initially a period of incomprehension and disbelief before those receiving the announcement take any action in response.

Had some warning been given, however, some people might have been able to hold on to handrails etc or sit down and thus reduce the number of injuries.

There was ample seating for all 1241 passengers. However, it would have taken some considerable time for all the passengers to have regained a seat, before the impact, particularly since the seats were on two deck levels. Even the action of sitting down in the position where they were standing would also have taken some considerable time because this would have crowded the accesses to the car deck.

Had the possibility of a berthing incident leading to a sudden deceleration been considered, it is likely that only one type of warning could have been made which might have reduced the number of injuries. This would have been a standard announcement to the passengers, made as the vessel approached Calais, to remain seated until a further announcement was made to proceed to the car decks. As soon as the vessel starts to proceed along the Calais entrance channel, it is normal for the passengers to start getting ready to go to the car decks. In the circumstances, such a warning would have had to be given almost at the time of stand-by if it were to be in any way effective. It is possible, however, that many of the passengers would have ignored such an announcement, and would still have congregated at the accesses to the car decks.

However P&O Stena and the ferry industry should consider whether suitable arrangements could be made to reduce the number of injuries in a similar accident.

2.8.2 Post-accident actions

Passenger reaction varied as to how the accident was handled, from those who praised the crew, to those who were extremely critical.

What is not in doubt is that it was some 10 - 15 minutes after the event before an authoritative broadcast, informing people what had happened, was made.

The common factor in such accidents is that those on the bridge are very often heavily occupied in handling post-accident events. In such circumstances, it is necessary to prioritise what is required and it may be that keeping the passengers informed is not necessarily considered to be the highest priority at the time. It is also possible that those on the bridge might themselves be suffering from various states of shock. In addition, post-accident stress can result in those on the bridge temporarily losing their concept of the passage of time. What they believe is an interval of only 1 or 2 minutes may in fact be 5 to 10 minutes. It is not, therefore, a case that those on the bridge are unaware of the need to inform people of what is happening. The person best placed to make the initial calm and authoritative broadcast is very often someone not directly involved in handling the accident or its immediate aftermath. The potential difficulty with this, however, is that such a person may not be fully familiar with all the necessary facts to enable them to make such an announcement. It would mean that those on the bridge would have to divert precious time to brief someone.

Nonetheless, management should give thought to how this requirement can be met.

A number of people, both passengers and crew, were injured in this accident. The injuries ranged from bruising to broken limbs. Many others were severely shaken. Everyone wanted to know what had happened, whether they were safe and what was going to happen next. In the aftermath of this accident, such information was, at best, patchy.

Providing regular, honest, authoritative and calm information is among the most important known of all requirements in any passenger-carrying vessel involved in an emergency. The need is extremely well known but, as this accident demonstrates, it is often overlooked. The difficulties are recognised, especially when the communication channels are likely to be clogged. It does, however, need to be addressed by management. P&OSL is recommended to re-examine its current procedures to ensure that even in the most unexpected situations, such a service can be reliably provided.

P&OSL Aquitaine did not carry a doctor, nor is she required to do so. Medical support can be readily provided from either France or England. A percentage of the crew will have had first-aid training, and there is always the prospect that on most passages some passengers will have had medical training. Such was the case on this occasion.

The call for medical support was both timely and well regarded. There were, however, indications that the ship's own ability to handle so many casualties in such a short space of time was overwhelmed. This was perhaps not surprising when there were a total of 1241 passengers on board and only 123 crew, half of whom would have been off-watch and sleeping a the time of the accident.

Having considered whether suitable arrangements could be made to reduce the number of injuries in a similar accident, P&OSL and the ferry industry should consider how casualties can be best supported.

2.8.3 Access to car decks

In normal circumstances, the master warns passengers to be ready to go to the car decks when the vessel is just over one ship's length from the berth. This accords with the MCA recommendations in MGN 19(M). Due to the problems the master was experiencing on this occasion, no such announcement was made.

Despite there being no announcement, a small minority of passengers had already made their way on to the car decks. They may have pre-empted an announcement because regular users of the cross-channel ferries realised that the vessel was almost alongside, and had anticipated the usual broadcast telling people to go to the car deck.

Passenger access to the car deck was possible because the car deck control panel had been operated to unlock the doors. If they had not been unlocked, passengers would have been unable to gain access to the car deck.

SECTION 3 - CONCLUSIONS

3.1 FINDINGS

1. *P&OSL Aquitaine* was correctly registered, licensed and manned by an experienced and qualified crew at the time of the accident. [1.11, 1.12]

2. *P&OSL Aquitaine* struck No 7 berth at Calais at 0939 BST on 27 April 2000 in fine weather and good visibility. [1.3]

3. There were 1241 passengers and 123 crew on board at the time of the accident. [1.2]

4. A total of 180 passengers and 29 crew were injured. The injuries ranged from bruising to broken limbs. There were no fatalities. [1.3, 2.8.2]

5. No 7 berth was badly damaged, and was out of use for several months. [1.9]

6. The vessel suffered damage to her bulbous bow and bow apron. Some vehicles on the car decks were also damaged. [1.9]

7. No announcement was made to the passengers by the master until about 15 minutes after the impact. [1.3]

8. The port CPP stand-by pump first cut in on the passage from Calais to Dover, almost 4 hours before the accident. [1.3]

9. The last change in pitch recorded by the CPP log of the port propeller was at 09.26.28. From this point the pitch remained constant at 70% ahead, until the vessel hit the quay some 11 minutes later. [1.6]

10. The port CPP shaft-driven pump was found to have two rotor vanes fractured. [1.5]

11. No warning announcement was made to the passengers of the impending impact with the quay. [1.3]

12. Some passengers had made their way on to the car decks without having been given permission to do so. Some of the injured were on the car decks. [1.3, 2.8.3]

13. The VDR was not functioning at the time of the accident, and was of no use to the investigation. [1.15]

14. The chief engineer considered the cutting in of the stand-by pump to be a minor problem, and did not inform the master at any time before the impact. [2.5]

15. The bridge team failed to notice that the port CPP failed to respond to the various demands being made. [2.5,2.6]

16. There is no clear indication in the ECR of demanded pitch. [2.3]

17. Calais port regulations restrict speed within Avant port to a maximum of 10 knots. P&OSL was not informed of this until June 2000 at which time they promulgated this instruction to their masters. [2.7]

18. On the starboard bridge wing console the port CPP pitch indicator is not clearly visible from where the master stands to berth the vessel. [1.16]

19. It is possible the demanded pitch on both CPPs was at full astern at the time of the impact. However the demanded pitch shown on the CPP recorder on both CPPs was 10% astern. [2.4]

20. LIPS had not identified the risk of partial failure of the shaft -driven pump and there was no alarm function on the high pressure side of the system. [2.3]

3.2 CAUSE

Unknown to the engine room and bridge teams, control of the port CPP was lost as the vessel was entering Calais. Consequently, on its approach to the berth in Calais, the master was unable to properly control the vessel to enable a safe and normal docking.

3.3 CONTRIBUTORY CAUSES

1. Port CPP control was lost because rotary vanes of the main shaft-driven pump were damaged.

   The pump was unable to produce sufficient pressure in the high pressure side of the CPP system to cause the blade pitch to change in response to movement of the pitch control combinator levers. Consequently the blades locked into the position achieved, that is 70% ahead pitch.

2. The engineers were unable to detect the fault in the shaft-driven pump of the port CPP system. The reasons for this were:

   - There was no facility for remotely monitoring the CPP system oil pressure, making it impractical to monitor the pressure continuously from the ECR.
   - The lack of an audible alarm facility to indicate low system oil pressure on the high pressure side of the system.
   - There was no obvious and convenient way for the engineers to monitor and compare bridge demand and achieved propeller pitch.
   - The system was not designed to give warning of low CPP pump delivery pressure.

- The operation and maintenance manual written in a language none of the engineers understood, and there was no fault-finding or trouble-shooting section.

3. Failure of the chief engineer to inform the master of the unusual cutting in of the port CPP stand-by pump.

4. Lack of awareness that anything was wrong with the port CPP system by the master and first officer because the response to changes on position of the combinator control levers were not monitored during manoeuvring.

SECTION 4 - RECOMMENDATIONS

The managers of P&O Stena Line are recommended to:

1. Ensure that CPP operation and maintenance manuals have a fault-finding facility and are written in the working language of the ship's engineer.

2. Provide clear indication in the ECR of demanded propeller pitch from the bridge.

3. Review its fleet regulations to ensure that the CPP bridge control systems are operating satisfactorily before leaving and entering port.

4. Review the need for remote monitoring of CPP system oil pressure in the ECR.

5. Ensure that all vessel's clocks/recording devices are correctly synchronised at all times.

6. Ensure, in the event of an accident, an announcement is made to the passengers as soon as possible to inform them of the situation.

7. Circulate throughout the fleet a reminder of the importance of fleet regulations being followed with regard to procedures for passenger access to the car decks.

8. Circulate throughout the fleet a reminder of the importance of fleet regulations being followed with regard to monitoring correct pitch orders.

9. Amend fleet regulations, shipboard operations, deck department Section 20.1 to "ensure that ***engine and*** helm orders are closely monitored" and remind the fleet deck officers the need to monitor the intended actions of the master/OOW as appropriate.

10. Consider what appropriate announcement may be made to the passengers before the vessel enters a port so that, in the event of an accident, the majority of passengers will still be seated. Hopefully, the number of those injured and the extent of their injuries can be minimised if this is achieved.

11. Re-examine its current procedures to ensure that, even in the most unexpected situations, regular, honest, authoritative and calm information can reliably be provided to passengers.

LIPS and International Association of Classification Societies (IACS) are recommended to:

12. Review the need for remote monitoring of CPP system oil pressure in ECRs.

13. Review the need for an audible alarm to indicate when there is insufficient oil pressure in the CPP system to move the blades under all conditions of loading.

14. Review the need for pitch indicators on bridge control consoles to be located together and in clear view of the operator.

15. Review the need for clear indication in ECRs of demanded and achieved propeller pitch from bridge.

SECTION 5 - ACTION TAKEN BY P&O STENA LINE SINCE THE ACCIDENT

1. Since the accident, and before the production of this report and recommendations, P&O Stena Line has taken the following action:

2. A follow-up alarm has been fitted to both port and starboard CPP systems giving audible and visual alarms on the bridge centre console. The alarms activate when 20% difference between demanded and achieved pitch occurs.

3. The bridge console pitch achieved indicators were fitted by the system manufacturers to read ahead to astern in a port to starboard configuration. These indicator gauges have been rotated through 90°to give an astern to ahead configuration.

4. The alarm facility using switch PRS3 has been installed to operate in the ECR, warning of low CPP operating oil pressure. This is set at between 25 and 40bar. The specific setting is to be decided by trial depending on actual system pressure fluctuations.

5. An additional VDU has been fitted in the ECR with cameras fitted on the bridge wings so that the engineers can monitor the ship's progress as seen from the bridge wings during passage and port operations.

6. A remote alarm indicator for the voyage data recorder has been fitted on the bridge.

Marine Accident Investigation Branch
July 2001

"CONSTANT"					"DEEP WATER"			
MOVEMENT RECORDER	INDICATED PITCH			PITCH DEMAND (CTR CONSOLE)	INDICATED PITCH			MOVEMENT RECORDER
	PORT	CTR	STB'D		PORT	CTR	STB'D	
70%	7.8	7.9	7.8	10	7.7	7.8	7.7	70%
60%	6	6	6	8	7.7	7.8	7.8	60%
40%	4.2	4.2	4.2	6	7.7	7.8	7.8	40%
20%	2.9	3	3	4	6.4	6.5	6.5	30%
20%	1.6	1.8	1.8	2	3.4	3.6	3.5	20%
0	0	0	0	0	0	0	0	0
-20%	-1.9	-1.8	-2	-2	-2.8	-2.6	-3	-20%
-40%	-3.2	-3.1	-3.5	-4	-5.2	-5.2	-5.5	-30%
-40%	-4.1	-4	-4.2	-6	-7	-7	-7	-50%
-60%	-5.5	-5.3	-5.7	-8	-7.6	-7.7	-7.8	-70%
-80%	-79	-78	-79	-10	-8	-7.8	-8	-90%

<u>STBD PROPELLER CALIBRATIONS</u>

"CONSTANT"					"DEEP WATER"			
MOVEMENT RECORDER	INDICATED PITCH			PITCH DEMAND (CTR CONSOLE)	INDICATED PITCH			MOVEMENT RECORDER
	PORT	CTR	STB'D		PORT	CTR	STB'D	
70%	4	7.9	7.8	10	7.8	7.8	7.8	70%
60%	4	5.8	5.8	8	7.8	7.9	7.8	60%
40%	4.2	4	4.1	6	7.8	7.8	7.8	40%
20%	3	2.8	2.8	4	6.4	6.3	6.2	30%
20%	1.6	1.7	1.7	2	3.4	3.2	3.1	20%
0	0	-0.1	-0.1	0	0	0	0	0
-20%	-2	-2	-2.1	-2	-3	-3	-3	-20%
-40%	-3.5	-3.6	-3.7	-4	-5.6	-5.6	-5.6	-30%
-40%	4.2	4.2	4.2	-6	-7	-7	-7.1	-50%
-60%	-6	-6	-6	-8	-7.7	-7.7	-7.8	-70%
-80%	-8	-7.9	-8	-10	-7.9	-7.8	-7.8	-90%