MAIB
MARINE ACCIDENT INVESTIGATION BRANCH

ACCIDENT REPORT

SERIOUS MARINE CASUALTY REPORT NO 14/2018 JULY 2018

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Catastrophic engine failure, resulting in a fire and serious injuries to the engineer on board *Wight Sky*, off Yarmouth 12 September 2017

SUMMARY

At 2133 on 12 September 2017, while approaching Yarmouth, Isle of Wight, the ro-ro passenger ferry *Wight Sky* **(Figure 1)** suffered a catastrophic failure of one of its main propulsion engines, followed by a fire. The fire was brought under control in less than 2 minutes, but the vessel's engineer, who had been standing near the engine, suffered serious burn injuries to his hands and face. Although he was discharged from hospital 7 days later, he was subsequently diagnosed with post-traumatic stress disorder.

Figure 1: *Wight Sky*

An examination conducted by the vessel's engine maker, Volvo Penta UK, concluded that the most probable trigger for the failure was debris in the engine's oil channels following rebuild. The MAIB investigation established the following:

- The engine had been completely rebuilt and failed after 5½ hours of operation.
- The vessel's soft patches[1] had not been removed, necessitating the engine to be lowered piecemeal into the engine room.

[1] Soft patches: steel plates bolted down and sealed flush with the vehicle deck, that can be removed to allow large pieces of ship's machinery or equipment to be removed/inserted.

- Debris could have entered the engine's oil channels during the 3 days that the partially assembled engine had been exposed to the elements.

- Analysis of oil samples from the engine indicated that accelerated wear had commenced before the engine failure.

- The power supply to the essential services switchboard, which distributed power to critical equipment including the fixed fire-extinguishing system, was lost 27 minutes after the accident.

Actions have been taken by the vessel's owner, Wightlink Limited, and by Volvo Penta UK, to address some of the issues identified in this report.

A recommendation has been made to Volvo Penta UK, to consider offering wear particle detection technology for marine engines that cannot be easily serviced on board.

FACTUAL INFORMATION

Narrative

On 12 September 2017, the ro-ro passenger ferry *Wight Sky* departed Lymington at 2100[2] for the 40-minute passage to Yarmouth. There were 40 persons on board.

Main propulsion engine 2 (ME2) had been put back into service following a complete rebuild by Volvo Penta authorised service engineers RK Marine Limited (RKM). The crew of the morning shift had tested ME2 off load and had verified that all alarms and shutdowns were functioning correctly. During the afternoon shift, the vessel's engineer tested the engine on load, and on departure from Lymington that evening all four main engines were sharing the sea load.

At around 2130, the engineer went down to the forward engine room from the machinery monitoring room (MMR), located on the main vehicle deck immediately above, to note the machinery running parameters for the logbook. He saw that the high temperature cooling water header tank for ME2 required topping up and, while he was filling the tank with coolant, he heard an unusually loud sound from the engine. The mechanic was attending to main propulsion engine 1 (ME1) located in the same space **(Figure 2a)**. At 2133:51, as the engineer rushed towards ME2's emergency shutdown button, there was a loud explosion from its crankcase **(Figure 2b)**.

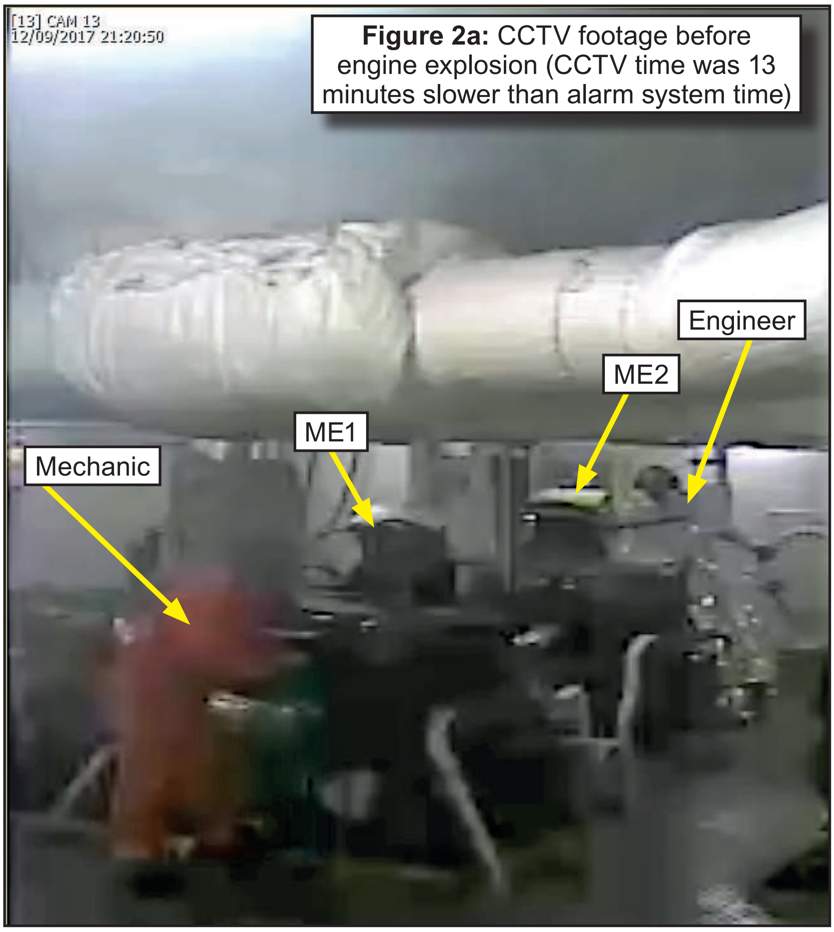

Figure 2a: CCTV footage before engine explosion (CCTV time was 13 minutes slower than alarm system time)

The engineer, who was wearing a full sleeved cotton boiler suit, was momentarily engulfed in a ball of fire and experienced intense pain. He ran out of the engine room and, assisted by the mechanic, went to the

[2] All times are UTC.

Figure 2b: CCTV footage showing engine explosion

MMR. They called the bridge using the talk back system and apprised the master of the situation. At the time, the master was making his approach to the ferry terminal, which was approximately 300m away. The bosun was at the wheel. The master abandoned berthing, and at 2135 released the Hi-fog[3] fire suppression system for the forward engine room.

The master observed on the closed-circuit television (CCTV) screen that the fire appeared to be extinguished less than a minute after the Hi-fog had been activated. On the master's order, the bosun made an announcement to inform the passengers of the incident and to reassure them that the situation was under control. The master then called the emergency services and asked for ambulance and fire services to attend the vessel at the berth. *Wight Sky* berthed at 2142 and all passengers and vehicles were disembarked in an orderly fashion. Meanwhile the ship's crew attempted to make the engineer comfortable.

Shortly after berthing, an ambulance with paramedics arrived on board *Wight Sky* and, after assessing the engineer, took him to the hospital. The fire brigade arrived at approximately 2200. When firefighters entered the engine room a few minutes later, the Hi-fog system had stopped. On inspecting the engine room, the firefighters found a small fire still burning inside ME2's crankcase. They extinguished this with a portable dry powder extinguisher.

On the afternoon of 13 September, *Wight Sky* was towed to Portsmouth for repairs. The damaged engine was replaced with a new one and the vessel was returned to service on 26 October.

The engineer suffered burns to his hands and face. Although he was discharged from hospital after 7 days, he was subsequently diagnosed with post-traumatic stress disorder. He had not returned to work at the time of publishing this report.

Sequence of events and damage observed

The following sequence of events was captured by the vessel's Kongsberg alarm recording and CCTV systems:

- 2133:08 ME2 lube oil pressure shutdown
- 2133:10 ME2 crankcase pressure; coolant level; common shutdown
- 2133:51 Explosion (CCTV footage)
- 2134:25 Fire alarm
- 2134:59 Hi-fog activated
- 2135:58 Fire apparently extinguished (CCTV footage)
- 2202:29 Hi-fog pump unit fault

[3] Hi-fog: Marioff Hi-fog System, a water mist-based fire suppression system.

Most of the visible damage was observed in and around cylinder unit 4 of ME2. The big end bearing was distorted radially **(Figure 3a)**, white metal had melted onto the bearing pin on the crankshaft **(Figure 3b)** and two of the four big end bearing bolts had sheared at the joining face between the top and bottom halves of the bearing keep. The outboard side of the crankcase was punctured **(Figure 3c)**, creating a large opening through which several components, including the gudgeon pin, connecting rod and fragments of the piston and cylinder liner had been ejected. There was fire damage on and around the engine **(Figure 3d)**.

Company and crew

Wightlink Limited (Wightlink) operated eight vessels on scheduled routes between the Isle of Wight and the south coast of England. Three sister vessels, *Wight Sky*, *Wight Light* and *Wight Sun* operated on the Lymington-Yarmouth route. The other vessels in the fleet, including two high speed vessels, operated on routes from Portsmouth to the Isle of Wight.

On the day of the accident *Wight Sky*'s crew comprised the master, mate, bosun, three deck ratings, an engineer and a mechanic. The master and engineer held STCW[4] certificates of competency appropriate to their ranks. The master had 7 years' experience and the engineer 26 years' experience in their respective roles on board Wightlink ferries.

Layout of machinery space and engine maintenance

Wight Sky had a Voith-Schneider cycloidal propulsion unit at each end of the vessel. Each propeller shaft was belt-driven by a pair of Volvo Penta D16C-A MH, six-cylinder engines, with an output of 485kW per engine at 1800rpm[5]. ME1 and ME2 were located in the forward engine room and ME3 and ME4 in the aft engine room. The Hi-fog fire-extinguishing system with its tanks, pumps and release switches was located in the space between the two engine rooms **(Figure 4)**.

There was an agreement between the vessel's classification society, Lloyd's Register, Wightlink and their service agents, RKM[6] that the Volvo Penta engines on all three sister vessels would be completely stripped down and examined every 16000 to 20000 hours. RKM had carried out 16 engine rebuilds on the three sister vessels, including that of ME2 of *Wight Sky*. The assembly of the engine's block complete with liners, pistons, connecting rods, bearings and crankshaft, but without the cylinder head or sump pan was referred to as the 'short block'. In all 16 instances, the short blocks were built in RKM's workshop and were delivered to the vessels' engine rooms via the emergency escape hatch. The water and oil channels, internal components and machined surfaces were protected by a loose plastic sheet during transit and while waiting to be lowered into the engine room.

Openings to engine room

Each engine room had a 0.69m by 0.69m emergency escape hatch on the starboard side leading to the vehicle deck above. The aperture of the hatch was restricted by a handrail and ladder. The short block was the largest engine assembly that could be moved through the hatch opening.

All of *Wight Sky*'s four main propulsion engines had a 'soft patch' in the deckhead directly above them that could be removed to permit the removal and replacement of complete engines **(Figure 5)**. Each opening was 3.85m by 1.95m and was closed with a steel plate bolted down and sealed flush with the vehicle deck. At the deckhead level in the engine room, the soft patch was insulated and covered over with cladding plates held in place by pop rivets. Opening the soft patch involved the removal of several items associated with the engine, including a large section of exhaust pipe, crankcase breather, engine lifting beam and several brackets supporting the pipes.

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[4] STCW - International Convention on Standards of Training, Certification and Watchkeeping for Seafarers 1978, as amended.

[5] rpm: revolutions per minute.

[6] The company carried out all the major servicing of Volvo Penta engines in the Wightlink fleet.

Figure 3: Damage to main engine 2

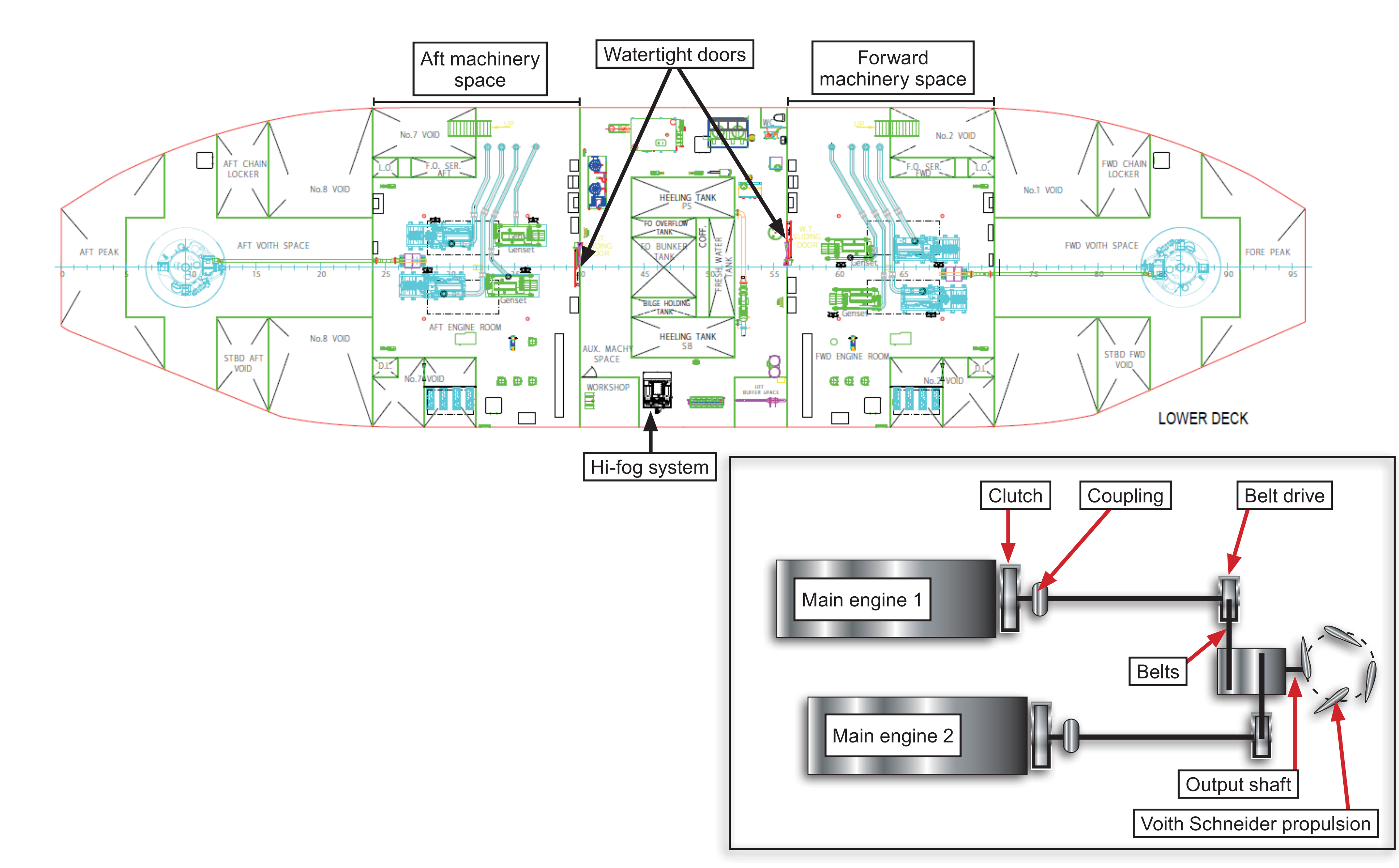

Figure 4: General arrangement of machinery spaces

Figure 5: Soft patch and escape hatch

Wightlink and RKM had agreed to move the engine in and out of the engine room using the emergency escape hatches.

In October 2017, the replacement ME2 was lowered into the engine room through the soft patch opening. It took external contractors 8 hours to remove the soft patch and 16 hours to refit it.

Previous engine failure on *Wight Sky*

In July 2017, ME2 developed a coolant loss problem. The ship's crew and RKM were unable to diagnose the cause of this. Several cooled components, including the turbocharger and associated exhaust piping, were replaced, but the problem persisted.

On 4 August, the cylinder head was replaced by RKM, but on testing the engine thick white smoke was observed at the engine exhaust. On 11 August, the turbocharger was replaced, when the engine was run up one of the two exhaust valves on cylinder unit 5 sheared, resulting in the lower half becoming embedded in the piston. The failure was not investigated but was attributed by RKM to incorrectly adjusted valve tappet clearances.

Engine rebuild

Following the failure of ME2 on 11 August, RKM, with the agreement of Wightlink, decided to complete a full rebuild of the engine. The work commenced on August 18 at RKM's workshop. The engine components used for the rebuild were a mixture of new and used components from other D16 engines in the fleet.

The crankshaft was polished and crack tested at a specialist workshop subcontracted by RKM. The crankshaft oil channels were blown through with compressed air before assembly. The engine block was pressure washed, dried and a rust inhibitor applied to its internal surfaces. The short bock was assembled using the polished crankshaft and new pistons, cylinder liners and bearing shells.

The short block and the remaining components of the engine were transported to Lymington ferry terminal on Friday, 25 August. There is conflicting evidence as to whether it was delivered on board and left on deck or remained on the quay. On 29 August, the Tuesday following the August bank holiday, the short block, cylinder head and sump pan were lowered separately into the forward engine room via the emergency escape hatch by Wightlink staff.

Between 29 August and 4 September, two diesel fitters from RKM completed the engine rebuild in *Wight Sky*'s engine room. At the time, they were unable to assemble the coupling connecting the engine to the output shaft as the thread of one of the coupling's bolt holes was damaged. On 4 September, RKM tested the engine uncoupled from the output shaft and left the vessel with instructions to the vessel's engineer to load test the engine once it had been connected to the output shaft.

Engine lubrication system

The lubrication system **(Figure 6)** consisted of a crankshaft-driven oil pump, which delivered the sump oil through two full flow filters of 40-micron mesh size and a third, part-flow filter of 10-micron mesh size. The total quantity of lubricating oil was 55 litres. An oil channel along the inboard side of the engine block conveyed the lubricating oil to the main bearings. From the main bearing the oil was fed to the big end bearing immediately forward of it through a drilled channel. Piston cooling and lubrication oil was carried through a separate channel on the outboard side of the block.

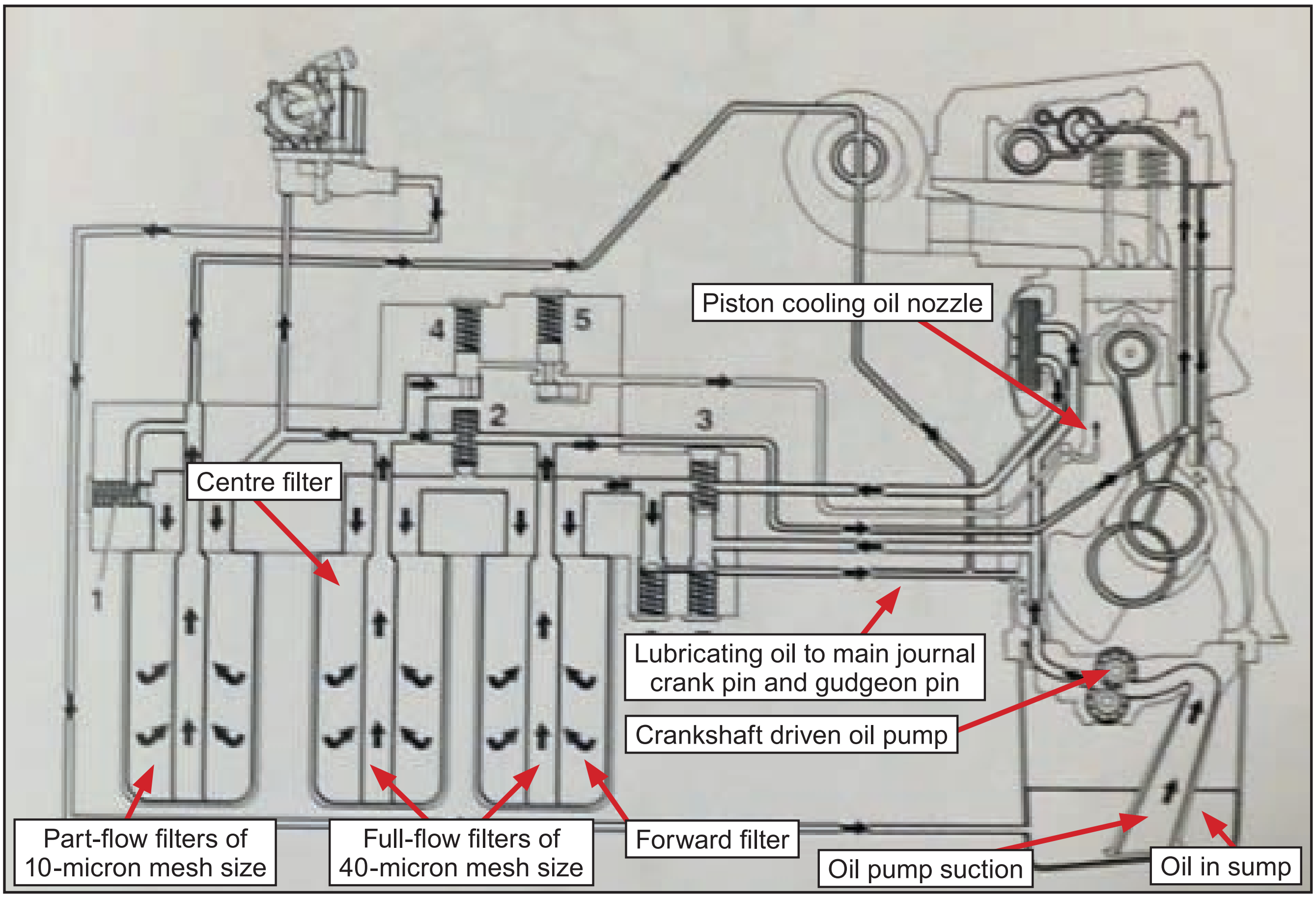

Figure 6: Engine lubricating oil system

Examination of the engine

Prior to the explosion, ME2 had been run for 5½ hours since its rebuild. On 19 September, the engine cylinder block, sump pan, clutch and external pipes of ME2 were removed by RKM in the presence of MAIB inspectors. The engine short block, with all the remaining components, was packed and delivered to temporary storage on 4 October and to Volvo Penta's UK head office at Warwick on 9 November.

On 15 November, specialist engineers from Volvo Penta, Sweden, examined the engine components in the presence of representatives of the MAIB, RKM and Wightlink. The tightening torque of the bolts on bearing keeps of all the undamaged main and big end bearings was checked and confirmed to be correct. The crankshaft journal dimensions were also checked to establish that they were true. Signs of overheating at main bearing 5 at the top end of its journal nearest to big end bearing 4 were observed. Upon dismantling main bearing 5, its shells were found to have turned **(Figure 7)**. Both the bearing shells and journal had suffered severe damage, but there was no remaining evidence of debris embedded in the bearing shells.

The investigation report by Volvo Penta concluded that, when the shells for main bearing 5 turned, they blocked the lubricating oil channel on the main journal leading from the journal to cylinder unit 4's crank pin. This caused the big end bearing to seize on the crank pin, leading to the failure of the bearing bolts. The rotating crankshaft then hit the unrestrained connecting rod, which impacted against the side of the crankcase, puncturing it and breaking the piston cooling oil gallery.

The report concluded:

> *We believe the breakdown was occurred due to remaining debris in the engine oil channels and the main bearing 5 after the overhaul. And also considering that the breakdown occurred only 5 hrs. after the refurbishment.* [sic]

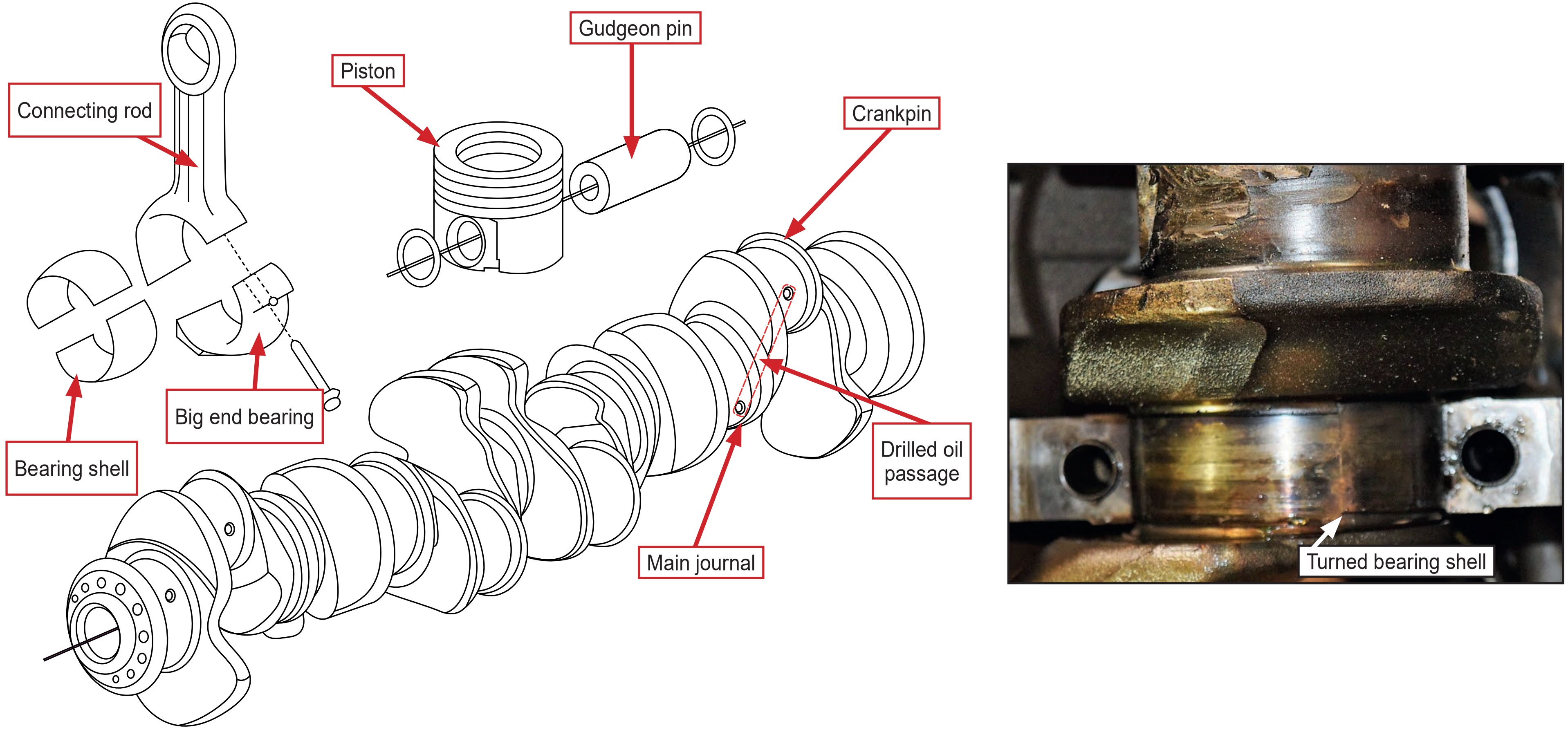

Figure 7: Schematic of crankshaft assembly

Tests carried out

The forward and centre filter **(Figure 6)**, along with oil samples from forward filter housing and the engine sump were analysed independently for their physical and chemical characteristics and accumulated wear particles.

The report on the analysis of particles in the filters stated:

> *Both of the oil filters tested contained high quantities of particulate matter...Some particles exhibited evidence of localised heating. Some of the particles observed were rather large (over 1mm in size).*

A few critical parameters are compared in **Table 1**.

	Oil from sump	Oil from forward filter
Iron (ppm[7])	17	8
Copper (ppm)	27	27
Lead (ppm)	18	13
PQ Index[8]	8	217
Water (ppm)	2472	279
Flash point - indication of fuel dilution (°C)	135	>200

Table 1: Comparison of test results of engine lubricating oil samples

To understand the mode of failure of the big end bearing bolts of cylinder unit 4, they were also independently tested. The test report concluded that *all bolts failed by ductile failure (either in tension or shear).*

The report further observed that the two bolts on one side of the bearing keep had failed in tension, and the two on the other side in shear.

Essential services switchboard

The forward and aft engine rooms had their own main switchboards. A common essential services (ES) switchboard was connected to each main switchboard by a dedicated circuit breaker. The ES switchboard supplied electrical power to critical equipment such as the water-mist fire suppression system[9] (Hi-fog), watertight doors, rescue boat davit, main hydraulic power pack and emergency lighting. The ES circuit breakers had an automatic and manual mode and were intended to be left in automatic mode so that irrespective of which main switchboard was in use, the critical equipment was not deprived of electrical power.

On the day of the accident, the forward switchboard was in use. It shut down just after 2200 after the electrical power supply automatically switched over to the aft switchboard. As a result of an earlier oversight, the ES circuit breaker for the aft switchboard had been left in the manual mode, so the ES switchboard was left without power. This caused the loss of all essential services, including the Hi-fog system.

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[7] ppm: parts per million

[8] PQ Index: A relative measurement of the total ferrous metal content of oil detected by magnetic field.

[9] The Hi-fog system had a reserve tank of water pressurised by nitrogen, sufficient to provide up to 60 seconds of coverage for the protected space.

Previous accidents and failures

In February 2018, D16 main propulsion engine on *Wight Light* shut down on low oil pressure. The analysis of the sump oil from the engine indicated a large amount of copper, lead and iron wear particles. Subsequent strip down examination of the engine by RKM, found that the main bearing shells of cylinder unit 2 had turned.

On 7 September 2017, the 15.87m crew transfer vessel, *Windcat 8*, was on passage to Grimsby, UK, from the Lynn Wind Farm in the North Sea with two crew and eight windfarm technicians on board. Shortly after setting off, the vessel's port engine, which was the same make and model as that on *Wight Sky*, suffered catastrophic damage and caught fire. The MAIB investigation[10] identified that one of the engine's connecting rod big end shell bearings had failed, resulting in the connecting rod assembly releasing and penetrating the engine crankcase.

In November 2015, *Wight Sun* suffered a failure of its D16 main propulsion engine. The cause of failure was established to be turned shells of a main bearing.

ANALYSIS

Immediate consequences of the accident

Wight Sky was approaching the ferry terminal at Yarmouth when ME2 exploded, causing a fire in the engine room and injuring the engineer.

The master was faced with a very difficult situation and, in co-ordination with the bosun, executed a series of quick actions that ensured the safety of the vessel, passengers and crew. The engineer was extremely fortunate that his injuries were not life threatening. The shrapnel ejected from the engine during the explosion thankfully missed him and, despite being engulfed in fire, his cotton boiler suit protected most of his body from the heat.

The consequences of this accident could have been far worse.

Accident mechanism

All the bolts from undamaged bearings had been torqued to the recommended levels, and metallurgical tests on the failed big end bearing bolts established that there was no evidence of fatigue. The engine ran for 5½ hours before the breakdown; had the engine been incorrectly assembled it is likely that the failure would have occurred soon after it had been started.

Volvo Penta's finding, that debris in the oil channels was the likely cause of the bearing shells turning, was not supported by direct evidence, such as embedded debris in the shells. However, debris of significant hardness and size, if lodged between the main bearing and crankshaft journal, has the potential to disrupt the hydrodynamic lubrication, resulting in metal to metal contact. This would be rapidly followed by the bearing shells turning, blocking the oil supply to the big end bearing, which then resulted in its failure.

Soft patches

The soft patches were not used to move the engines in or out of the engine rooms due to the disruption their removal would cause. Therefore, RKM planned its work around the use of the emergency hatch. This required the engines to be partially disassembled and rebuilt in the engine room, transporting the majority of the components in the short block.

[10] MAIB Report 1/2018, catastrophic engine failure, resulting in a fire on board *Windcat 8* off the Lincolnshire coast.

The source of any debris that might have entered the oil channels cannot be known for certain. However, ME2's short block had been exposed to the elements for 3 days with only a loose plastic sheet for protection, and debris could have entered the oil channels during this time.

Rebuilding the entire engine under a clean and controlled environment and transferring it directly into the engine room through the soft patch would have significantly reduced the likelihood of debris ingress during transit and while awaiting fitting.

Analysis of test results

The test results of the sump oil sample revealed high levels of water and fuel contamination that were not present in the oil sample from the filter. Since the mechanically-driven lubricating oil pump would have stopped with the engine, the filter oil sample was representative of the engine oil's condition before the explosion. The contamination of the sump oil was a result of the damage and subsequent fire suppression.

The presence of a high number of particles larger than 10 microns as indicated by a high PQ index **(Table 1)**, combined with a low count of small iron particles in the oil sample from the forward filter, suggests a sudden and rapidly progressing wear-down. The unusually large wear particles in the filters, some of which were larger than 1mm, also implies that accelerated wear had started before developing into a catastrophic failure. This wear-down probably started before the main bearing shells turned, since the total starvation of oil supply would have resulted in nearly instant seizing of the big end bearing, giving insufficient time for the wear particles to find their way to the filter. Therefore, the wear particles exhibiting heat damage were most likely to have been from main bearing 5, generated before the bearing shells turned.

It is evident from the alarm logs that the lubricating pressure shutdown was activated a few seconds before the explosion. By that time, the damage had already been done. As the engine was not fitted with a particle detector or other means of detecting rapidly progressing wear, there was no possibility of receiving an early warning before the engine failed. The previous accident on *Windcat 8* and other failures on sister vessels of *Wight Sky* could also have potentially been prevented had a particle detector system been fitted.

Loss of power to essential services

When the power supply for *Wight Sky* switched from the forward to aft switchboard, the ES switchboard lost all power because the dedicated ES circuit breaker had been left in the manual mode. As a result, the Hi-fog system, along with the watertight doors and several other pieces of critical equipment, lost electrical power.

The Hi-fog system was very effective in extinguishing the fire within a minute of having been activated. However, had the changeover to the aft switchboard taken place immediately after the accident, the Hi-fog system would have provided further protection for only 60 seconds, increasing the potential for re-ignition and growth of the fire. There were several fuelled vehicles parked on the deck directly above the forward machinery space, so the consequences of the loss of electrical power to the ES switchboard could have been very serious.

To avoid the loss of power to critical equipment, the importance of the ES switchboard circuit breakers needs to be recognised and suitable controls established to ensure these are not routinely left in the manual mode.

CONCLUSIONS

- The consequences of this accident could have been far worse; the engineer was fortunate that his injuries were not life threatening, and the quick actions of the bridge team ensured the safety of the vessel, passengers and crew.
- Volvo Penta's investigation into the engine failure concluded that:
  - Debris in the engine's oil channels was most probably responsible for initiating the failure.
  - When the shells of main bearing 5 turned, the lubrication supply to big end bearing 4 was blocked, resulting in destructive failure.
- Rebuilding the engine in a clean and controlled environment and transferring it complete into the engine room would have reduced the likelihood of debris ingress.
- The engine was not fitted with a wear detector, so there was no means of receiving a warning before the engine failed.
- The essential services switchboard aft circuit breaker had been left in manual mode, resulting in the loss of power to critical equipment, including the fixed fire-fighting system.

ACTION TAKEN

Wightlink Limited has:

- Agreed with RKM that all engines will be fully assembled and load-tested prior to delivery on board.
- Put in place signage to ensure that the circuit breakers for the essential services switchboard are correctly set at all times.

Volvo Penta UK has:

- Written to all Volvo Penta dealerships in the UK and Ireland to provide guidance on good practice for repair and rebuild and to ensure that:
  - Volvo Penta UK is informed of any major engine failure resulting in injury, fire or flood.
  - Where appropriate, soft patches are removed to allow removal and reinstallation of complete engines.
  - Engine assembly is completed in a clean environment to prevent debris being built into an engine.
  - Following rebuilds, engines are load-tested on a dynamometer and certificates issued confirming the required performance.
  - Records of component measurements are kept to confirm that they are within tolerance and fit for reuse.

RECOMMENDATIONS

Volvo Group (UK) Ltd is recommended to:

2018/120 Consider offering wear particle detection technology for Volvo Penta marine engines that cannot be easily serviced on board.

Safety recommendations shall in no case create a presumption of blame or liability

SHIP PARTICULARS	
Vessel's name	*Wight Sky*
Flag	United Kingdom
Classification society	Lloyd's Register
IMO number/fishing numbers	9446984
Type	Ro-ro passenger ferry
Registered owner	Wightlink Limited
Manager(s)	Wightlink Limited
Year of build	2008
Construction	Steel
Length overall	62.40m
Gross tonnage	2546
Minimum safe manning	10
Authorised cargo	Passengers, private and commercial vehicles
VOYAGE PARTICULARS	
Port of departure	Lymington
Port of arrival	Yarmouth (Isle of Wight)
Type of voyage	Internal waters
Cargo information	19 motor vehicles, 30 passengers
Manning	10
MARINE CASUALTY INFORMATION	
Date and time	12 September 2017, 2133
Type of marine casualty or incident	Serious Marine Casualty
Location of incident	50°42'.41 N, 1°30'.03 W (300m from Yarmouth ferry terminal)
Place on board	Forward engine room
Injuries	Severe burn injuries to engineer
Damage/environmental impact	Main propulsion engine 2 damaged beyond repair
Ship operation	In service
Voyage segment	Arrival
External & internal environment	Moderate sea, light breeze
Persons on board	40