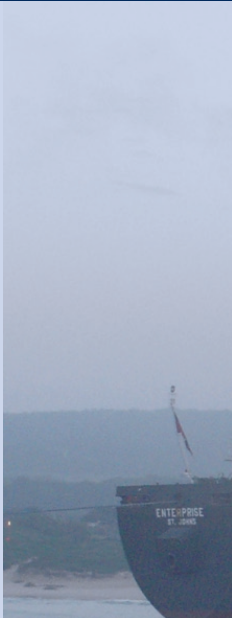




Australian Government

Australian Transport Safety Bureau



ATSB TRANSPORT SAFETY INVESTIGATION REPORT  
Marine Occurrence Investigation No. 229  
Final

Independent investigation into the main engine failure  
on board the self discharging bulk carrier

# Enterprise

in Bass Strait

10 July 2006



**Australian Government**  

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***Enterprise***

**in Bass Strait  
10 July 2006**

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### Abstract

At about 1540 on 10 July 2006, while the self-discharging bulk carrier *Enterprise* was in Bass Strait, Australia, an alarm sounded indicating that the main engine lubricating oil pressure was low. When the duty engineer started changing over to a second filter, lubricating oil pressure was lost; causing the engine to stop and the ship to black-out. The engine was restarted and the passage was resumed.

At 1805, the main engine low lubricating oil pressure alarm sounded again. At 2000, after further inspections had been undertaken, the chief engineer advised the master that the main engine could not be run due to probable bearing damage and that the ship would need to be towed to the nearest port for repairs. The main lubricating oil pump was also found, at this time, to have failed.

The ship was towed into Melbourne, arriving on 15 July, where all main and bottom end bearings were inspected. A large gouge mark was found on one bottom end bearing.

Further investigations revealed that the gudgeon pin in number five piston had failed when a pre-existing, undetected flaw led to fatigue cracking of the gudgeon pin. The engine manufacturer had not provided sufficient guidance for monitoring the fatigue life of gudgeon pins or for inspecting gudgeon pins for cracks.

The investigation also found that maintenance planning for the main lubricating oil pump was inadequate in that maintenance was not undertaken according to the manufacturer's instructions, despite the fact that the pump had failed previously.

The execution of routine maintenance on the lubricating oil filter was also inadequate in that the spare filter was not ready for use. The shipboard procedures did not identify the error and the procedures for operating and monitoring the filter were also ineffective.

The report makes three recommendations to address the identified safety issues with the aim of preventing other similar occurrences.

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# THE AUSTRALIAN TRANSPORT SAFETY BUREAU

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The Australian Transport Safety Bureau (ATSB) is an operationally independent multi-modal Bureau within the Australian Government Department of Transport and Regional Services. ATSB investigations are independent of regulatory, operator or other external bodies.

The ATSB is responsible for investigating accidents and other transport safety matters involving civil aviation, marine and rail operations in Australia that fall within Commonwealth jurisdiction, as well as participating in overseas investigations involving Australian registered aircraft and ships. A primary concern is the safety of commercial transport, with particular regard to fare-paying passenger operations.

The ATSB performs its functions in accordance with the provisions of the *Transport Safety Investigation Act 2003* and Regulations and, where applicable, relevant international agreements.

## **Purpose of safety investigations**

The object of a safety investigation is to enhance safety. To reduce safety-related risk, ATSB investigations determine and communicate the safety factors related to the transport safety matter being investigated.

It is not the object of an investigation to determine blame or liability. However, an investigation report must include factual material of sufficient weight to support the analysis and findings. At all times the ATSB endeavours to balance the use of material that could imply adverse comment with the need to properly explain what happened, and why, in a fair and unbiased manner.

## **Developing safety action**

Central to the ATSB's investigation of transport safety matters is the early identification of safety issues in the transport environment. The ATSB prefers to encourage the relevant organisation(s) to proactively initiate safety action rather than release formal recommendations. However, depending on the level of risk associated with a safety issue and the extent of corrective action undertaken by the relevant organisation, a recommendation may be issued either during or at the end of an investigation.

The ATSB has decided that when safety recommendations are issued, they will focus on clearly describing the safety issue of concern, rather than providing instructions or opinions on the method of corrective action. As with equivalent overseas organisations, the ATSB has no power to implement its recommendations. It is a matter for the body to which an ATSB recommendation is directed (for example the relevant regulator in consultation with industry) to assess the costs and benefits of any particular means of addressing a safety issue.



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## TERMINOLOGY USED IN THIS REPORT

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**Occurrence:** accident or incident.

**Safety factor:** an event or condition that increases safety risk. In other words, it is something that, if it occurred in the future, would increase the likelihood of an occurrence, and/or the severity of the adverse consequences associated with an occurrence. Safety factors include the occurrence events (e.g. engine failure, signal passed at danger, grounding), individual actions (e.g. errors and violations), local conditions, risk controls and organisational influences.

**Contributing safety factor:** a safety factor that, if it had not occurred or existed at the relevant time, then either: (a) the occurrence would probably not have occurred; or (b) the adverse consequences associated with the occurrence would probably not have occurred or have been as serious, or (c) another contributing safety factor would probably not have occurred or existed.

**Other safety factor:** a safety factor identified during an occurrence investigation which did not meet the definition of contributing safety factor but was still considered to be important to communicate in an investigation report.

**Other key finding:** any finding, other than that associated with safety factors, considered important to include in an investigation report. Such findings may resolve ambiguity or controversy, describe possible scenarios or safety factors when firm safety factor findings were not able to be made, or note events or conditions which 'saved the day' or played an important role in reducing the risk associated with an occurrence.

**Safety issue:** a safety factor that (a) can reasonably be regarded as having the potential to adversely affect the safety of future operations, and (b) is a characteristic of an organisation or a system, rather than a characteristic of a specific individual, or characteristic of an operational environment at a specific point in time.

Safety issues can broadly be classified in terms of their level of risk as follows:

- **Critical safety issue:** associated with an intolerable level of risk.
- **Significant safety issue:** associated with a risk level regarded as acceptable only if it is kept as low as reasonably practicable.
- **Minor safety issue:** associated with a broadly acceptable level of risk.



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## EXECUTIVE SUMMARY

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On 10 July 2006, the Antigua and Barbuda registered self-discharging bulk carrier *Enterprise* was en route from Adelaide with a cargo of canola seed for discharge in Newcastle and soda ash for discharge in Sydney. At about 1540<sup>1</sup>, a low pressure alarm sounded for the main engine lubricating oil system.

The main lubricating oil filter was due for scheduled maintenance so the duty engineer decided to change over to the standby filter. When he opened the valves to put the standby filter on line, the oil pressure at the engine inlet dropped quickly and the main engine shut down on low oil pressure. The main engine driven generator had been on line to provide electrical power so, when the main engine stopped, all electrical power was lost. The engine was restarted and the passage was resumed.

At 1805, when *Enterprise* was approximately 8 miles<sup>2</sup> northeast of Hogan Island in Bass Strait, the main engine low lubricating oil pressure alarm sounded again. The engineers stopped the engine at 1817.

The chief engineer carried out a main engine crankcase inspection and saw flecks of metal in the bottom of two of the crankcase spaces. At about 1830, he advised the master that the main engine may be seriously damaged and that further inspections were being undertaken. At 2000, he further advised the master that the main engine could not be run due to probable bearing damage and that the ship would need to be towed to the nearest port for repairs. The chief engineer discovered, at this time, that the main lubricating oil pump had also failed.

By 0930 on 11 July, the wind had freshened to about 30 knots from the northwest. The seas were rough with a moderately heavy swell. At 1400, the port anchor was walked back<sup>3</sup> to slow the drift of the ship and the ship anchored in 60 metres of water.

A towage contract was negotiated and the tug *Keera* started towing *Enterprise* to Melbourne at 1400 on July 13. At 1853 on 15 July, *Enterprise* berthed at number 29 South Wharf, Melbourne.

All main and bottom end bearings were inspected in Melbourne and a large gouge mark was found on one bottom end bearing. After the damaged bearings were replaced, engine trials were conducted. After the trials, it was noticed that there were metal flecks again under number four and five pistons. Further investigations revealed that the gudgeon pin in number five piston had failed and that the piston skirt was damaged. Number five piston and liner were replaced before engine trials were successfully conducted.

The ATSB's examination found that the gudgeon pin failed because of a pre-existing flaw. This flaw was undetected, and undetectable, by the ship's engineers. The subsequent fatigue cracking of the pin remained undetected until the gudgeon pin failed. The failure of the gudgeon pin was followed by damage to the piston skirt. Metal debris from the failed gudgeon pin and piston skirt was collected in the lubricating oil filter and this caused the filter to choke. When the duty engineer changed over to the standby filter, it had not been primed and was not ready for

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1 All times referred to in this report are local time, Coordinated Universal Time (UTC) + 10 hours.

2 A nautical mile of 1852 m.

3 Lowered under power.

service. The resulting loss of oil pressure to the engine may have initiated the failure of the bottom end bearing.

It was not possible to accurately determine when the engine driven lubricating oil pump failed. The evidence suggests that it had been running in a damaged condition before the engine breakdown led to the pump's failure being discovered.

The report identifies the following safety issues and makes recommendations to address them:

- The engine manufacturer did not provide sufficient guidance for monitoring the fatigue life of the gudgeon pin or for inspecting the gudgeon pin for early signs of impending failure.
- The maintenance for a critical piece of equipment, the main lubricating oil pump, was not planned according to the manufacturer's recommendation, despite the fact that a previous failure had occurred.
- The shipboard procedures and practices for operating, maintaining and monitoring the K8E lubricating oil filter were inadequate. The standby filter was not checked to ensure that it was ready for use and the in-service K8E filter's condition was not adequately monitored.

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# 1 FACTUAL INFORMATION

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## 1.1 *Enterprise*

*Enterprise* is a self-discharging bulk carrier (Figure 1) registered in Antigua and Barbuda. The ship was owned by Zweite Belt Shipping and managed by AJ Ship Management, Germany. It was classed with Det Norske Veritas (DNV) as a  $\times$ 1A1 Bulk Carrier<sup>4</sup> E0<sup>5</sup>.

The ship was built in 1985 by Mitsubishi Heavy Industries in Shimonoseki, Japan. It was originally named *Torgnes* and was renamed *Enterprise* in 1996. It has an overall length of 113.01 m, a beam of 20.21 m and a depth of 9.48 m. The ship has a deadweight of 8709 tonnes at its summer draught of 8.29 m.

**Figure 1:** *Enterprise*



At the time of the incident, *Enterprise's* crew of 16, comprised a master and three mates, chief and three engineers, chief and four integrated ratings, two catering staff and a trainee. All of the crew were Australian nationals.

The mates on board *Enterprise* maintained the traditional four hours on, eight hours off watchkeeping system. The engineers operated a 24 hour duty roster system with the engineers performing maintenance between 0800 and 1700 each day; the engine room remained unmanned outside of these hours.

The master of *Enterprise* held an Australian master class one certificate of competency. He had been at sea since 1958 and had been master on board the ship since June 2005.

The chief engineer held an Australian engineer class one certificate of competency (steam and motor) issued in 1996 and had been at sea since 1979. He had been chief engineer on the ship since July 2004 and he had rejoined *Enterprise* on 28 June 2006.

The first engineer held an Australian class two certificate of competency (motor) issued in 1981. He had been at sea since 1976 and had nine years experience on board *Enterprise*. He had rejoined the ship in Adelaide, less than one week before the incident.

---

4 Designed and constructed to DNV rules.

5 Engine control and alarms outside the engine room allowing for an unmanned machinery space.

## 1.2 Machinery systems

### 1.2.1 The main engine

*Enterprise's* propulsion was provided by a medium speed, marine diesel engine that drove a controllable pitch propeller, and a shaft generator, through a reduction gearbox. The SEMT Pielstick 6PC2-5L diesel engine was manufactured under license by Nippon Kokan Kabushiki Kaisha at its Tsurumi works in Japan.

Figure 2: Engine top

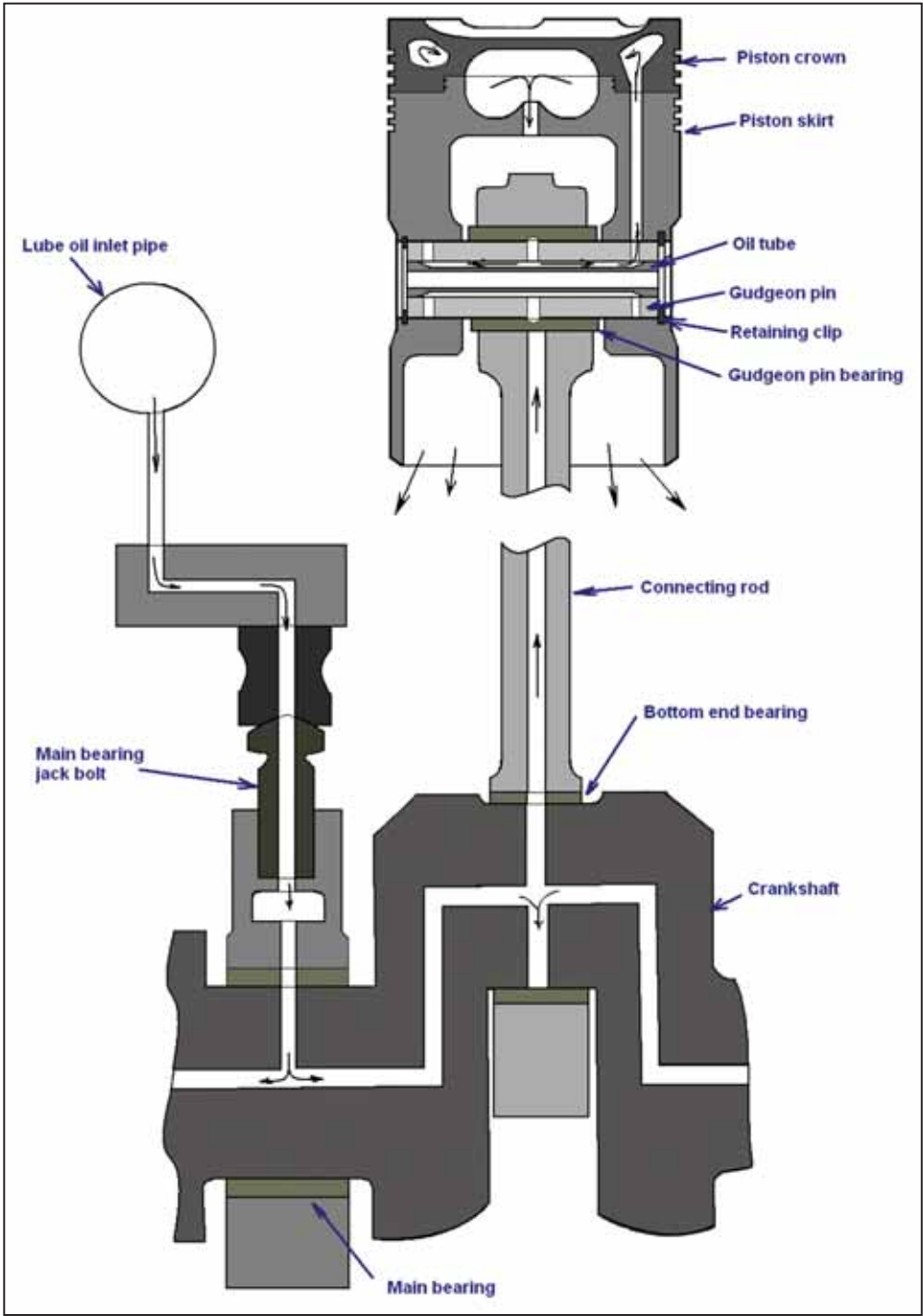


The engine was a non-reversing, single-acting, four-stroke, turbo charged, trunk-piston engine that ran on heavy fuel oil. It was fitted with a single VTR354 turbocharger. The engine had a bore of 400 mm, a stroke of 460 mm and developed 2582 kW at 502 rpm.

At the time of the incident, three of the engine's six pistons were manufactured from a single steel casting and the remaining three were a newer design, composite piston with a steel crown and aluminium skirt that were bolted together (Figure 3).

Each main engine piston assembly consisted of a piston, a connecting rod and a gudgeon pin that joined the connecting rod to the piston. Each piston ran inside a water-cooled, replaceable steel cylinder liner.

**Figure 3: Piston cross section showing internal oil pathways**



The gudgeon pins were machined from rolled steel and surface hardened to improve their wear characteristics. Each gudgeon pin was hollow, with oil holes drilled through from the centre to the outside, and contained a steel tube to provide the inner wall of the oil path. The gudgeon pin bearing consisted of a steel bush with a copper layer that was lined with white metal. The original clearance between the gudgeon pin and the bush was between 0.30 mm and 0.35 mm. The design clearance between the gudgeon pin and the piston was between 0.005 mm and 0.032 mm with a maximum clearance, due to wear, of 0.12 mm.

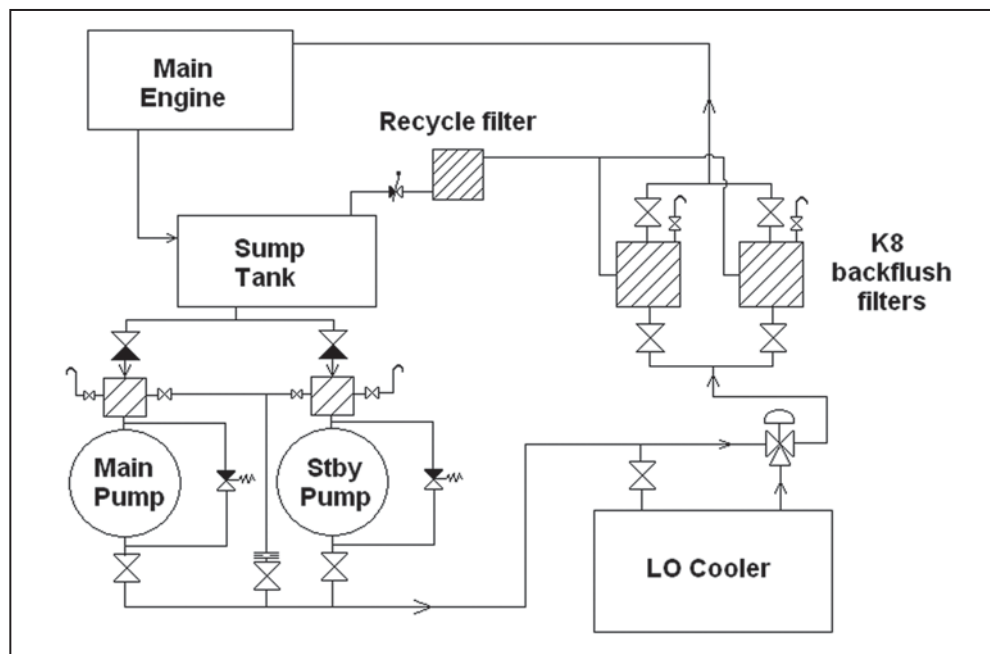
Each piston (Figure 3) was connected directly to the crankshaft by a connecting rod. The bottom end bearings at the crankshaft were all thin walled shell bearings with a thin white metal film cast over a copper layer on a steel backing. The bearings were manufactured in two halves to allow for removal. The bearings had a design clearance of between 0.35 mm and 0.458 mm. The manufacturer's replacement criterion for the bottom end bearing shells was when the white metal was worn to expose the copper layer for one third of the bearing area.

The engine had seven internal main bearings and one external main bearing, located between the engine and the reduction gearbox. These bearings were all of similar construction to the bottom end bearings. The main bearing design clearance and replacement criterion were the same as for the bottom end bearings.

## 1.2.2 Main engine lubrication system

The oil for the main engine lubricating oil system was stored in a sump tank situated below the engine. Oil drained directly from the crankcase back to the sump tank. The sump normally contained about 7000 litres of oil.

Figure 4: Lubricating oil system schematic diagram



There were two lubricating oil pumps fitted to the system; the main pump was engine driven and the standby pump was electrically driven. Oil was drawn from the sump tank by either lubricating oil pump through suction strainers. The oil then passed through the lubricating oil cooler, where the temperature of the oil was controlled by diverting some oil around the cooler using a bypass valve. The oil

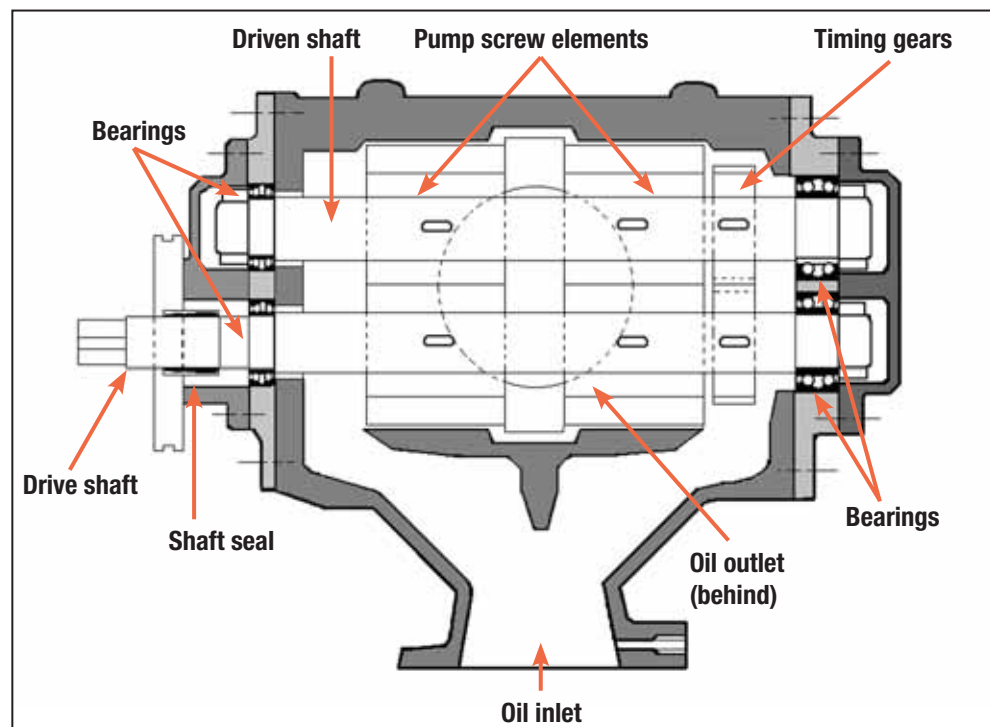
passed from the cooler to the final K8E automatic back-flushing filter and then to the engine oil inlet rail (Figure 4).

The lubricating oil was supplied to the engine through the main oil inlet pipe. From there, it flowed into each main bearing and into oil-ways drilled into the crankshaft (Figure 3). The oil flowed along the oil-way to each bottom end bearing and then up an oil-way inside the connecting rod to lubricate the gudgeon pin bearing and into the piston to cool it; before returning to the bottom of the crankcase and draining back to the sump tank.

A priming line was fitted so that either lubricating oil pump, and its suction strainer, could be primed when the other pump was running. The shipboard routine for preparing the engine room for sea required that the standby pump was run to circulate oil through the engine and to prime the main pump and K8E filter at that time.

The oil in the sump tank was cleaned using a Mitsubishi Selfjector SJ 3000 centrifugal separator. The separator was designed to remove water, carbon and other suspended particles from the oil. The separator pump drew oil from the sump and passed it through a heater before discharging it to the separator. The clean oil was then returned to the sump tank. The separator continually discharged any water removed from the oil and, periodically, discharged the solids collected in the separator bowl by activating a de-sludge cycle.

**Figure 5: Main lubricating oil pump schematic drawing**

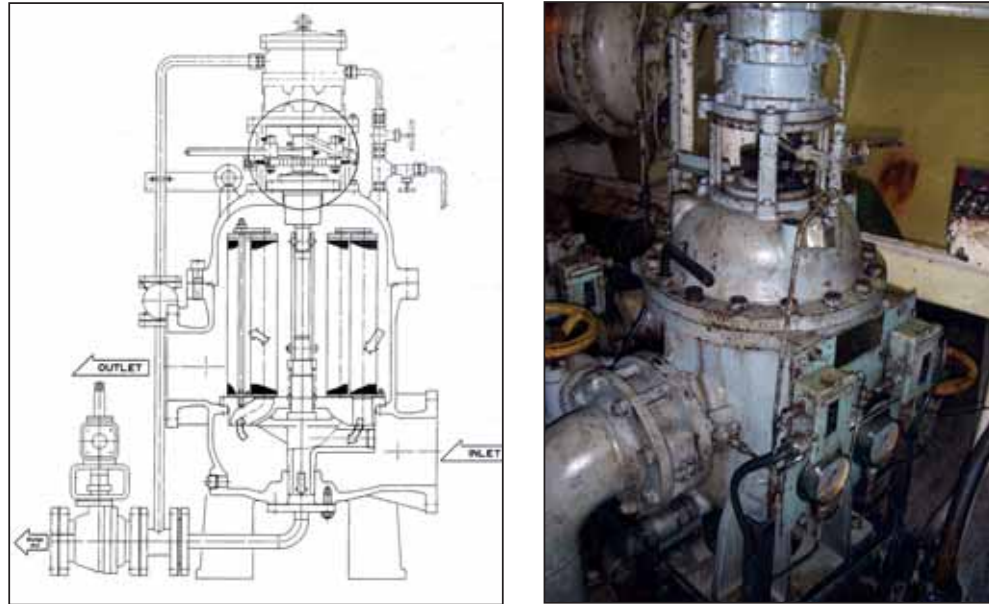


The main oil pump (Figure 5) was a Taiko FSU-60-4M1 horizontal, twin rotor, screw pump driven by the main engine through a Rexford flexible coupling. The pump had a discharge capacity of 80 m<sup>3</sup>/hour at a pressure of 7.5 kg/cm<sup>2</sup>. The pump consisted of a main rotor and a sub-rotor that were meshed together. Timing gears ensured that the rotors turned together. Each rotor was supported by a roller bearing at the coupling end and a ball bearing at the gear end. Each rotor had both a clockwise and counter-clockwise screw element. Oil flowed into the inlet port and

was divided at the entry to the screws and was continuously discharged from the centre of the pump.

The standby oil pump was a Kosaka vertical screw pump driven by an electric motor. It had a discharge capacity of 70 m<sup>3</sup>/hr at a pressure of 7.5 kg/cm<sup>2</sup>. This pump could be started and stopped manually or switched to automatic operation. When switched to automatic it would start if the main oil pressure fell to 4.0 kg/cm<sup>2</sup> and stop when the main oil pressure exceeded about 4.5 kg/cm<sup>2</sup> and the main engine speed was above about 450 rpm.

**Figure 6: K8E filter schematic and photograph**



The final filter for the lubricating oil was a K8E back-flush filter (Figure 6). The K8E filter was a notched wire design which removed particles larger than 30 microns from the oil. The oil flowed through the filter elements (candles), continuously. When the backpressure across the filter increased, a differential pressure switch initiated a back-flush cycle and each candle was back-flushed to clean it. The back-flushed oil returned to the sump by way of a mesh recycling filter. Each time the filter initiated a back-flush cycle, it was recorded on a counter. Two K8E filter units were fitted in parallel, one in service and one on standby, so that they could be changed over, if necessary, while the main engine was running. When the filter is clean, it back-flushes about 15 times per day. When the filter is due for cleaning, the back-flush counter will register about 80 to 90 cycles per day.

### **1.2.3 The electrical system**

*Enterprise* is fitted with a shaft generator, rated at 220 kW, which is driven directly from a power take-off fitted to the main engine reduction gearbox.

The ship also has two auxiliary diesel driven generators, each rated at 290 kW. Each generator is powered by a Daihatsu 6DS-19A diesel engine that runs on a blend of diesel and heavy fuel oil.

The ship's normal electrical load is carried on the shaft generator when the ship is at sea. In the event of an unplanned main engine stoppage which results in the

loss of electrical power, a 'black-out', a standby auxiliary generator should start automatically, connect to the main switchboard and restore the ship's power.

There is no emergency generator installed on board *Enterprise*.

### 1.3 The incident

On 8 July 2006, *Enterprise* departed Adelaide with a cargo of canola seed for discharge in Newcastle and soda ash for discharge in Sydney. 'Standby engines' was rung at 1812 and 'full away' at 1924.

At 0840 on 9 July, the main engine lubricating oil separator automatically shut down. The separator had previously shut itself down during the voyage from Portland to Adelaide. As a result of the separator problems, the chief engineer decided to test the water content in the main engine lubricating oil. It was found to be 1.9 per cent, higher than the engine manufacturer's recommended maximum of 1 per cent. At 1600, the chief engineer stopped the engine for a crankcase inspection to locate the source of the water ingress. Some condensation was observed returning from the crankcase breather drain line but no other signs of water ingress were found. The ship's engineers suspected that the most likely reason for the high water content was poor purification by the separator. No other abnormalities were noticed while carrying out this inspection. The engine was restarted at 1630 and the passage was resumed.

On 10 July, the separator was again observed to be not operating as it should have been. The separator was cleaned and the dam ring was replaced. The water content was subsequently tested and found to be 1.45 per cent, indicating to the engineers that the separator was now operating more effectively.

At about 1540, a low pressure alarm sounded for the main engine lubricating oil system. The main engine lubricating oil inlet pressure had fallen to 4.5 kg/cm<sup>2</sup>. The duty engineer acknowledged the alarm and investigated the cause. The number two K8E filter was on line and had a high differential pressure. The filter counter showed that it had back-flushed 228 times in the preceding 24 hours.

The filter was due for scheduled maintenance so the duty engineer decided to change over to the number one filter. When he started to open the inlet valve to put the number one filter on line, the oil pressure at the engine inlet dropped quickly. The standby oil pump started automatically but the pressure continued to fall until the main engine low oil pressure shut-down activated when the pressure fell below 3.5 kg/cm<sup>2</sup>, stopping the main engine.

The shaft generator was on line to provide the ship's electrical power so, when the main engine stopped, all power was lost. The standby auxiliary generator then started automatically and restored power. All systems were reset, the filters were changed over and the main engine was restarted by 1600.

The number two filter was stripped and inspected. It was found to be dirty but there were no obvious signs of metal or other abnormal debris.

The duty engineer checked around the engine room before leaving it unmanned at 1700. The main engine lubricating oil pressure and the lubricating oil filter differential pressure were normal and nothing abnormal was noticed.

At 1805, when *Enterprise* was approximately eight miles northeast of Hogan Island in Bass Strait, a main engine low lubricating oil pressure alarm again sounded and the standby oil pump started automatically. The duty engineer responded to

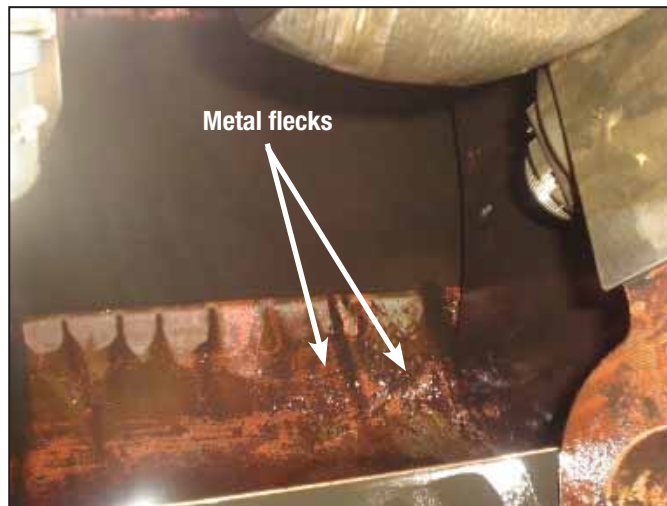
the alarm and also called the chief engineer. Main engine power was reduced and control of the engine was transferred to the engine control room. At 1817, the engineers stopped the main engine.

The main lubricating oil pump suction strainer was opened for inspection and found to contain flecks of metal. At about 1830, the chief engineer advised the master that the main engine was possibly seriously damaged and that further inspections were being undertaken.

A crankcase inspection was carried out by the chief engineer and flecks of metal were seen in the bottom of number four and number five crankcase spaces (Figure 7).

At 1855, the master advised the rescue coordination centre (RCC) that the ship's engine had broken down and that the ship was drifting but was not in danger (Figure 8). The wind was from a north by west direction at 18 knots<sup>6</sup> with a moderate sea of two to three metres. *Enterprise* drifted in a 170° (T) direction at 0.8 knots and was unable to anchor because it was close to a submarine gas pipeline.

**Figure 7: Metal flecks in the bottom of number five crankcase.**



At 2000, the chief engineer advised the master that the main engine could not be run due to probable bearing damage and that the ship would need to be towed to the nearest port for repairs.

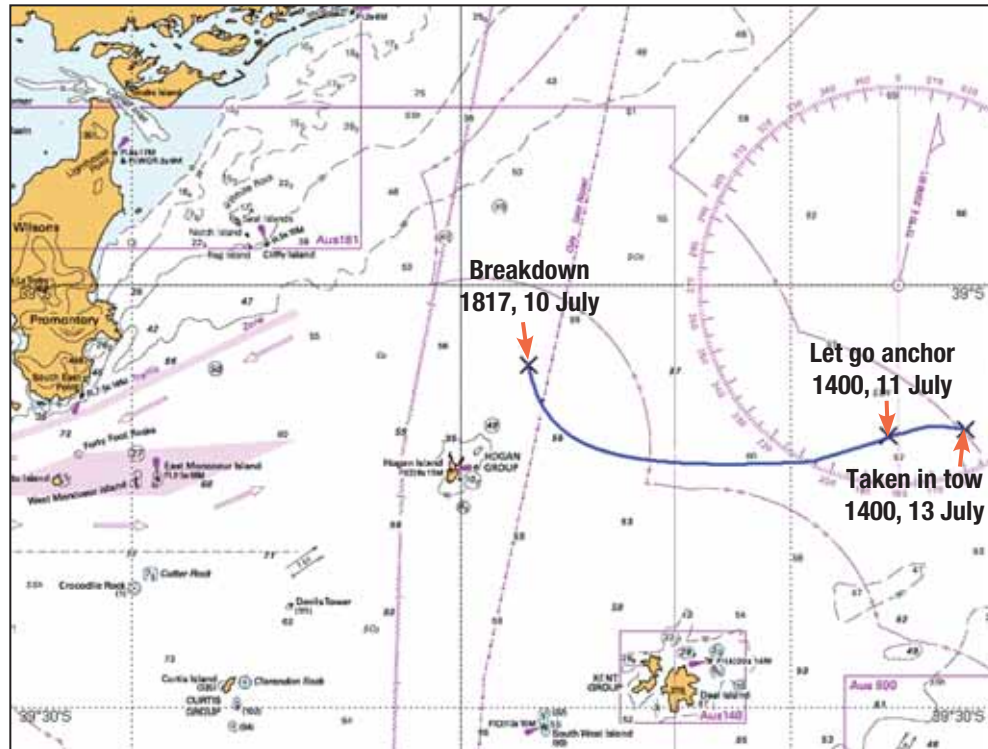
At this time, attempts to reinsert the main oil pump suction strainer were frustrated by an obstruction in the filter housing which was caused by broken pieces of a lubricating oil pump screw. The main oil pump was dismantled and inspected. One bearing was found to have failed and the screw elements were damaged with pieces missing.

By 0930 on 11 July, the wind had freshened to about 30 knots from the northwest. The seas were rough with a moderately heavy swell. *Enterprise* was drifting at 1.7 knots in an easterly direction but was not in any immediate danger.

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<sup>6</sup> One knot, or one nautical mile per hour equals 1.852 kilometres per hour.

Figure 8: Extract from navigational chart Aus 802 showing ship's drift



At 1400, the port anchor was walked back to five shackles<sup>7</sup> of anchor cable in the water to slow the drift of the ship and to hold the ship's bow toward the wind. The anchor dragged briefly before the ship settled securely at anchor.

A towage contract was finalised with Adsteam Marine at about 2000 on 11 July and the tug *Keera* sailed from Melbourne at about 1600 on 12 July. *Keera* rendezvoused with *Enterprise* at 1155 on 13 July, connected a tow line and then started to tow *Enterprise* to Melbourne at 1400.

At 0939 on 15 July, a harbour pilot boarded *Enterprise* for the transit into Port Phillip. The tug *Tusker* assisted the ship to navigate the channels into the bay. *Keera* released the tow for the trip up river and the tug *Gabo* assisted with berthing. By 1853, *Enterprise* was berthed at number 29 South Wharf, Melbourne, after an uneventful tow.

All main and bottom end bearings were inspected in Melbourne. A large gouge mark was found on number six bottom end bearing and a mark was found on the corresponding crankshaft journal. There was very little evidence of particle scouring or particle damage to the bearings examined, but some small pieces of metal were found on top of number five main bearing cap. The engineers concluded at the time that the metal that was observed in the crankcase had originated from the number six bottom end bearing

Two pistons were removed from the engine for inspection, number four, which had the longest running hours and was the next piston due for an overhaul, and number six, to ensure that there was no damage to the small end bearing bush after the damage was discovered in the bottom end bearing. No obvious signs of damage were noticed on either of these pistons.

7 One shackle equals 90 feet or 27.43 metres.

All of the damaged components were replaced before engine trials were carried out. When the crankcase doors were removed after three hours of engine trials, there was evidence of metal scattered around the crankcase under number four and number five cylinders. The only sign of damage on number five piston was very fine flecks of aluminium in the oil droplets from the bottom of the piston skirt.

On 29 July 2006, number five piston was removed from the engine. The gudgeon pin was found to have catastrophically failed and the piston skirt was also damaged (Figure 9). The cylinder liner was also removed from the engine.

**Figure 9: Number five piston and gudgeon pin**



A new piston and cylinder liner were fitted to the engine before engine trials were successfully conducted.

The cylinder liner was subsequently cleaned, honed, examined and calibrated before being retained as a spare.

*Enterprise* sailed from Melbourne, bound for Newcastle, at 0600 on 1 August 2006 to complete the voyage from Adelaide.

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## 2 ANALYSIS

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### 2.1 Evidence

On 16, 17 and 24 July 2006, investigators from the Australian Transport Safety Bureau (ATSB) attended *Enterprise* while it was berthed in Melbourne. The master and directly involved crew members were interviewed and they provided accounts of the incident. Copies of relevant documents were obtained including log book entries, statutory certificates, maintenance records, procedures and permits.

The damaged piston and gudgeon pin from number five cylinder were sent to the ATSB technical analysis laboratory in Canberra for examination. Samples of system lubricating oil and some of the metal fragments from the lubricating oil recycling filter were also examined.

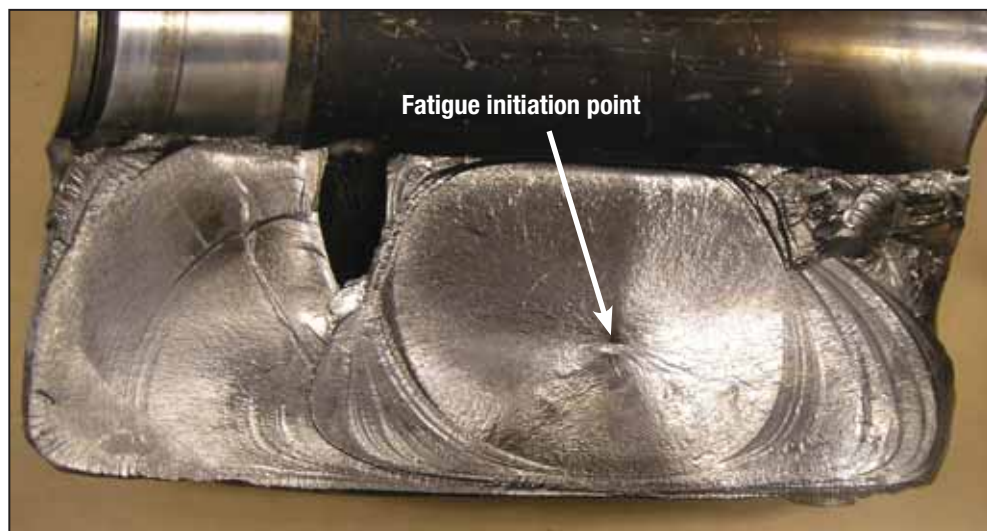
Information relating to the incident was also obtained from Australian Maritime Safety Authority (AMSA).

#### 2.1.1 ATSB examination of the physical evidence

An examination of the failed piston and gudgeon pin by the ATSB found evidence that the gudgeon pin almost certainly failed before the piston.

The gudgeon pin presented multiple, intersecting planes of transverse and longitudinal fatigue cracking. Although having primarily failed as a result of fatigue cracking and fracture along a central transverse plane, the suspected initial origin of fatigue cracking was located at an internal, mid-thickness position (Figure 10), and had initiated a single, longitudinal (radial) plane of cracking, which had developed through the full section thickness and for the full length of the gudgeon pin. Transfer of stresses and loss of rigidity associated with the growing longitudinal cracks resulted in the initiation and development of transverse cracking and the eventual structural failure of the gudgeon pin, as observed. The obvious mechanical damage and staining on fracture surfaces of the gudgeon pin suggested that the fatigue crack growth was over an extended period of time.

**Figure 10: Gudgeon pin failure**



The source of the microscopic flaw that led to the failure was not determined but could only have been present from the time that the gudgeon pin was manufactured.

Cracking was observed on the inner and outer surfaces of the piston skirt, with cracks running through the piston skirt where the gudgeon pin was located. These areas also showed evidence of material loss. The damage sustained by the piston was likely to have been a consequential result of the gudgeon pin cracking and failure.

It is doubtful that the piston failure was the result of the loss of lubrication on 9 July. There was no evidence of heat damage and there was evidence of relatively slow crack growth within the gudgeon pin. It is more likely that there would have been heat damage and a rapid overload type fracture if the loss of lubrication had directly contributed to the failure.

Interruption to the normal flow of lubricant and the generation of increasing amounts of wear debris as a result of the pin cracking would both have been expected to contribute to the observed breakdown of the engine systems.

The sample of oil taken from the main engine sump did not reveal any visible signs of metal contamination. An analysis of the flakes of metal retrieved from the recycle filter found that the flakes were mostly aluminium, probably from the skirt of the composite piston in number five cylinder.

## **2.2 The incident**

From the examination of the damaged parts, a probable failure sequence can be deduced. The gudgeon pin was almost certainly the first component to fail, followed by the piston skirt. The metal from the failed gudgeon pin and piston skirt was collected in the K8E filter and this caused the filter to choke. When the duty engineer changed over to the second K8E filter, it had not been purged of air following its previous service. The momentary loss of oil flow to the engine when this filter was put into service may have initiated the damage of number six bottom end bearing when the loss of oil allowed the journal to come into contact with the bearing shells.

It was not possible to accurately determine when the engine driven lubricating oil pump failed. It is possible that it had been running in a damaged condition for an extended period of time before the failure of number five gudgeon pin, the event that led to the discovery of the damaged pump.

## **2.3 Maintenance**

Preventative maintenance and inspection work is required to ensure that equipment is capable of operating as designed and to reduce the likelihood of failures in service. Equipment manufacturers recommend service intervals and procedures for their equipment. If these are not observed, equipment can fail without warning.

### **2.3.1 Main engine cylinders**

Overhauling a cylinder is a routine maintenance task on a marine diesel engine to ensure that the components of that cylinder have not worn excessively and are fit to continue service. The engine manufacturer recommends that the pistons are removed for inspection every 10 000 running hours.

As part of a cylinder overhaul on board *Enterprise*, the piston assembly is removed from the cylinder liner. The connecting rod is then removed from the piston to allow the piston to be cleaned and to inspect the gudgeon pin bearing. All of the components are cleaned and inspected visually, then the piston and cylinder liner are measured to ensure that the wear is within the manufacturer's defined limits. The connecting rod is checked for ovality in way of the bottom end bearing. The serrations, where the bearing cap bolts onto the connecting rod for the bottom end bearing, are checked for cracks using a non destructive test such as a dye penetrant check. The engine manufacturer's instruction manual contained no specific service requirements for the gudgeon pin.

The bottom end bearings are inspected and are replaced if they have exceeded their wear limit or are damaged. The bearing clearances are measured and recorded.

#### *Number five piston and gudgeon pin*

At the time of the incident, the main engine had run for a total of 95 378 hours. Number five cylinder had run for 1784 hours since its last overhaul in February 2006.

On 22 February 2006, number five piston was overhauled at 93 594 engine hours as part of the routine maintenance programme. The top compression ring was broken and the second ring had lost its tension. The piston was cleaned and fitted with new piston rings. It was noted in the second engineer's workbook that 'the piston will have to be changed next overhaul' because of wear in the ring grooves. A new liner was calibrated and fitted when measurements indicated that the existing liner had exceeded its wear limit.

The gudgeon pin was visually inspected and measured to ensure that it had the correct fit in the piston and to determine the bearing clearance in the connecting rod. The measurements were found to be within the manufacturer's specifications. There were no obvious flaws found on the outer surface of the gudgeon pin.

The initial crack that led to the failure of the gudgeon pin was both longitudinal and inside the bore of the gudgeon pin. It is unlikely that this would have been detected by a visual inspection during the last cylinder overhaul before the failure. While a fine crack would be difficult to locate using a purely visual inspection, the chances of finding a flaw would have been significantly improved if other methods of crack detection were used.

The gudgeon pins in the engine are individually numbered. The gudgeon pin that failed was number 1404, it had been classification society approved in 1983 and had been fitted in number five cylinder when the engine was first built. The individual numbers can be used to track the history of particular gudgeon pins through the engine but, in this case, the gudgeon pin's history had not been tracked. It is, therefore, impossible to determine the exact running hours and service conditions of the failed pin; although it is likely that it had run for the full 93 378 engine hours. The fact that it was still located in number five cylinder suggests that it had remained in that cylinder the entire time.

The engine manufacturer's maintenance manual did not specify any inspection or replacement regime for the gudgeon pins and they had not issued any service bulletins relating to gudgeon pins. While some engine components suffer from fatigue and are scheduled for replacement at a particular service interval, the engine manufacturer had not identified a risk of fatigue failure of gudgeon pins and had no service requirements for them. Consequently, there was no information regarding gudgeon pin failures or methods for checking the pins for early signs of failure.

There was a pre-existing, undetected, flaw in the number five cylinder gudgeon pin. The fatigue cracking that developed from this flaw went undetected until the gudgeon pin failed. The engine manufacturer did not provide sufficient guidance for monitoring the fatigue life of the gudgeon pin or for inspecting the gudgeon pin for early signs of failure.

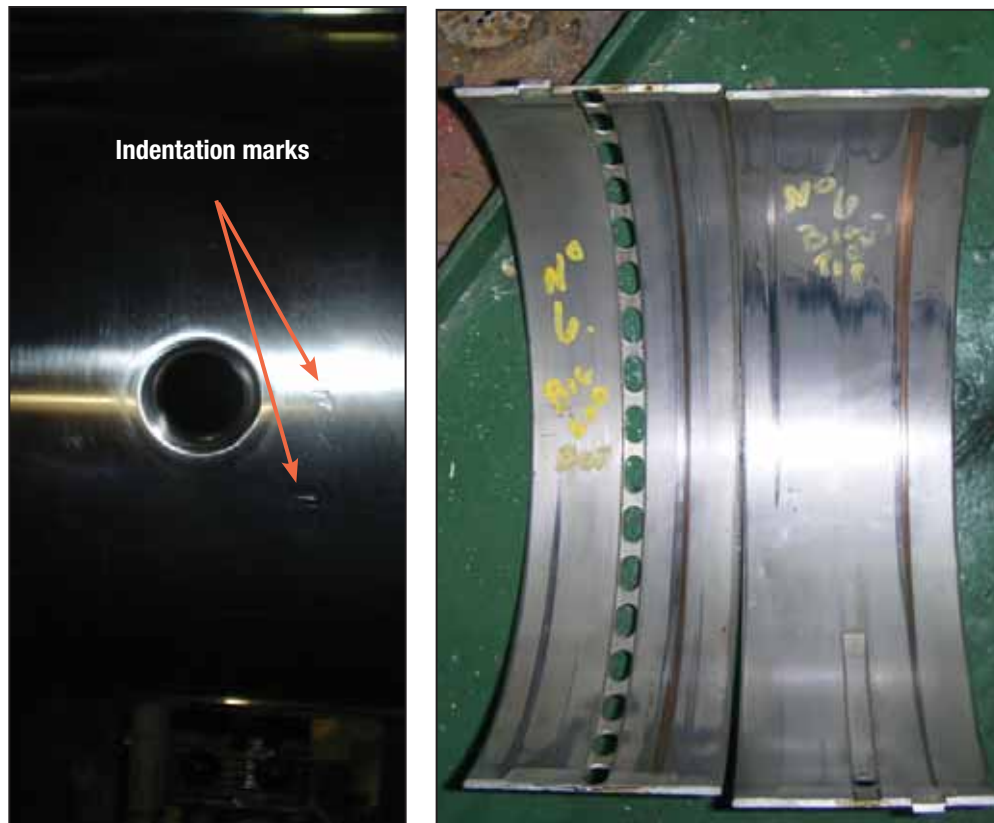
***Number six bottom end bearing***

On 4 January 2006, number six piston was overhauled at 92 950 engine hours as part of the routine maintenance programme. The bottom end bearing was renewed at this time. When the engine failed on 10 July 2006, the number six bottom end bearing had run for 2428 hours.

Following the incident, an indentation mark was observed on the crankshaft journal (Figure 11) consistent with the connecting rod making hard contact with the journal during reassembly. This probably occurred during a previous overhaul when the piston and connecting rod assembly was being lowered into the cylinder liner.

It was also reported that a small piece of white metal and copper was found in the bearing on disassembly, in line with the mark on the journal, but that this piece of metal had fallen out of the bearing when it was disassembled for inspection. This piece of metal is consistent with bearing material being gouged from the surface of the bearing shell by contact with the indentation mark on the journal.

**Figure 11: Number six crank pin and bottom end bearing**



Normally, a crankshaft journal is separated from the bearing shell by a wedge of lubricating oil that is formed by the relative movement of the parts while they are being lubricated with oil under pressure. In this instance, the damaged journal probably came into contact with the bearing shell when the oil film was disrupted due to the loss of lubricating oil pressure as the filters were changed over on 10 July.

### 2.3.2 K8E filter

The K8E filters were a routine maintenance item in the *Enterprise's* computerised maintenance management system (CMMS) and were scheduled to be changed over and cleaned every three months. The recycle filter was checked and cleaned monthly. This maintenance was carried out to ensure that the standby filter was ready for immediate use when required.

The normal maintenance instructions for this filter service were listed in the CMMS work order for the task:

1. Close all associated service valves.
2. Open vent to release pressure inside the filter.
3. Slowly open the filter and take out the filter element.
4. Clean inside the casing to be free from sludge.
5. Assemble the filter, open the service valves and certain the absence of leak.

When the service was complete the standby pump was normally run to prime the filter before it could be checked for leaks. The filter was then ready for use and could then be isolated and left as a standby unit.

The last service was completed on number one K8E filter on 10 April 2006 at 94 210 main engine running hours. This filter was left as the spare, or standby, filter.

At 1200 on 10 July, the number two K8E filter had done 228 back-flushes in the previous 24 hours. When the low oil pressure alarm occurred because of the high pressure differential across the filter, the duty engineer decided to change over to the standby filter. The duty engineer did not check that it was ready for service before he put it on line and, when he started opening the inlet valve, the lubricating oil pressure to the engine dropped, causing the main engine to stop. Checking that the standby filter is fully primed before putting it on line is a standard procedure and good engineering practice.

In the experience of the engineers, a higher than average back-flush count could occur when the lubricating oil separator fails to remove water from the oil causing the K8E filter to back-flush more frequently trying to remove sludge from the oil. The trend of an increase in the back-flush counter was considered to be an indicator that the lubricating oil separator was not performing efficiently.

While the high back-flush count was probably partly due to the high water content, it was probably also the result of debris from the failing number five piston accumulating within the filter. When the number two filter's elements were cleaned after the ship was disabled, minute particles of ferrous metal were washed out of them. There was a significant quantity of metal flecks in the recycle filter, which were subsequently determined to be aluminium.

The presence of metal flecks in the recycle filter indicates that metal particles of a relatively large size had passed through the lubricating oil pump suction strainers. A subsequent examination of the main pump's suction strainer revealed a small tear in the mesh.

The execution of the routine maintenance task of cleaning the filter was ineffective. The full instructions were not followed for servicing the K8E lubricating oil filter, resulting in it being left unprimed. Furthermore, it was not checked before it was put into service. This ineffective maintenance led to the loss of lubrication in the main engine, which may have initiated the damage found in number six bottom end bearing.

### **2.3.3 Engine driven lubricating oil pump**

On 13 November 1999, the engine driven lubricating oil pump was disassembled for inspection and survey. It was discovered, at that time, that both ball bearings at the forward end of the pump had collapsed, probably due to fatigue. The forward end of the pump scrolls had also been damaged with the leading edges broken off. All of the pump bearings were renewed and the pump screws were replaced with spares at 64 663 main engine running hours. It was noted during this inspection that the after end of the pump screws being inserted had been damaged and repaired at some time in the past.

On 23 November 2005, the flexible coupling failed on the pump when the mounting bolts for the pump worked loose, putting the pump and coupling out of alignment. The pump was realigned and resecured. An inspection of the pump revealed that the ball bearings were 'worn but serviceable'. The bearings could not be replaced because the ship did not have any suitable spare bearings on board at the time so the pump was returned to service and new bearings were ordered. The subsequent receipt of the spare bearings did not alert the engineers to the fact that the pump's bearings needed to be replaced.

After broken pieces of pump were found in the suction filter on 10 July 2006, the pump was again disassembled. One of the ball bearings had failed (Figure 12), probably due to fatigue, and the forward ends of both pump screws were damaged. An examination of the damaged pump screw pieces revealed that they had started to wear after they had broken off the shaft. Some broken pieces were more worn than others, indicating that they had failed at different times, and that the oldest failure did not appear to be recent.

The main engine had run for a total of 95 378 hours when the pump was found, on 10 July, to have failed. The pump had run for 30 715 hours since the bearings were replaced in 1999.

The manufacturer's instruction manual details the maintenance requirements for the lubricating oil pump. The ball bearings should be inspected every four years or 20 000 running hours. If any sign of damage or exfoliation is evident then the bearings should be replaced. The coupling should be inspected every 12 months or 8 000 running hours and parts renewed if they show signs of abnormal wear.

The inspection of the pump bearings was not included as a routine maintenance task in the CMMS. Following the failure of the pump bearings in 1999 and again after worn bearings were noted following the coupling failure in 2005, the inspection of the pump bearings was still not included in the CMMS; although the regular inspection of the coupling had been added to the CMMS in November 2005.

**Figure 12: Broken pump scrolls and collapsed pump bearing**



The planning of maintenance for the main engine driven lubricating oil pump was ineffective because regular inspections of the pump bearings, in accordance with the manufacturer's recommendations, were not programmed in the ship's CMMS. The pump bearings had previously failed and had been allowed to run for 30 715 hours since repairs after that failure, despite the manufacturers recommended bearing service interval of 20 000 hours. Furthermore, a previous failure of the pump bearings had not resulted in updating the planned maintenance system for the inclusion of the required pump bearing inspections.

## **2.4 Shipboard procedures**

Checklists and procedures were included in the AJ Ship Management safety management system (SMS) documentation for the preparation of the engine room for both departure and arrival. The purpose of the procedures was to ensure that the equipment was correctly used and monitored and that the standby equipment was ready for use. The checklists in the SMS for engine operation were generic but prescribed the basic steps required for each of these tasks. The checklists had been augmented by detailed procedures that were included in the chief engineer's standing orders folder.

Checking that the second, stand-by, K8E filter was fully primed was not a checklist or procedure item. The in-service K8E filter was primed and bled before the ship sailed from each port but, when 'Stand-by Engines' was rung, the standby K8E filter had not been checked.

The daily inspection of the K8E filter was detailed in the 'Duty Engineer Watchkeeping Duties' procedure that was included in the chief engineer's standing orders folder. This procedure states:

Check M.E. lube oil K8E auto cleaning filter for correct operation. It alarms at about 1 kg/cm differential pressure. When clean normally 6.8 kg in and 6.4 kg out. When the outlet pressure drops to 4.8 kg or alarm diff Press, change over and clean filters. M.E. will shut down at 4.0 kg.

As part of the engine room daily log, the duty engineer is also required to record the back-flush counter at 1200 each day in the log book before resetting the counter to zero. When the main engine is not running, the K8E filter is also shut down and, consequently, the back-flush counter will not need resetting to zero.

In the days leading up to the engine failure, the counter was recorded on 3 July (149 counts), 4 July (95 counts), 9 July (154 counts) and the day of the failure, 10 July (228 counts). Each of these records was in excess of what was normally

expected from the filter immediately before it was due for cleaning but no action was taken by the engineers to investigate the high counts, including the count of 228 recorded less than four hours before the engine problems began to occur. The back-flush counts represented an average of about nine back-flush cycles for every hour that the main engine ran, more than double the expected rate for a filter that was due for cleaning.

The shipboard practices and procedures for ensuring that the standby lubricating oil filter was ready for service, for monitoring lubricating oil filter performance and for changing over to the standby filter were inadequate.

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## 3 FINDINGS

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### 3.1 Context

During *Enterprise's* voyage from Adelaide, South Australia to Newcastle, New South Wales, the ship's main engine failed in Bass Strait, leaving the ship drifting for three days until it was towed into Melbourne, Victoria.

From the evidence available, the following findings are made with respect to the incident on board *Enterprise* and should not be read as apportioning blame or liability to any particular organisation or individual.

### 3.2 Contributing safety factors

- A pre-existing flaw in the number five cylinder gudgeon pin was undetected, and undetectable, by the ship's engineers. The subsequent fatigue cracking of the pin went unnoticed until the gudgeon pin failed.
- The engine manufacturer did not provide sufficient guidance for monitoring the fatigue life of the gudgeon pin or for inspecting the gudgeon pin for early signs of impending failure. *[Safety issue]*
- The main engine lubricating oil K8E filters probably became choked as a result of the volume of debris from the failed gudgeon pin and piston skirt.
- The shipboard procedures and practices for operating, maintaining and monitoring the K8E lubricating oil filter were inadequate. The standby filter was not checked to ensure that it was ready for use and the in-service K8E filter's condition was not adequately monitored. *[Safety issue]*
- There was probably a brief period of oil starvation to the engine when the lubricating oil K8E filter was changed over. The damage to the bottom end bearings may have occurred from the loss of lubricating oil supply, allowing an indentation on the crankshaft journal to come into contact with the bearing shell.
- The engine driven lubrication oil pump bearing probably failed due to fatigue. The pump's bearings had previously failed in a similar manner. The pump had run for 30 751 hours, far in excess of the manufacturer's recommended inspection schedule of 20 000 hours.
- The engine driven lubrication oil pump scrolls probably failed as a consequence of the pump bearing failure.
- The maintenance for a critical piece of equipment, the main lubricating oil pump, was not planned according to the manufacturer's recommendation, despite the fact that a previous failure had occurred.  
*[Safety issue]*

### 3.3 Other key findings

- The decision by the chief engineer not to run the main engine was justified given the likelihood of bearing, and possibly other, damage that was indicated by the presence of metal flecks in the crankcase.



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## **4 SAFETY ACTIONS**

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### **4.1 ATSB recommendations**

#### **MR20070027**

The engine manufacturer did not provide sufficient guidance for monitoring the fatigue life of the gudgeon pin or for inspecting the gudgeon pin for early signs of impending failure.

The Australian Transport Safety Bureau recommends that SEMT Pielstick, and its licensees, take action to address this safety issue.

#### **MR20070028**

The maintenance for a critical piece of equipment, the main lubricating oil pump, was not planned according to the manufacturer's recommendation, despite the fact that a previous failure had occurred.

The Australian Transport Safety Bureau recommends that AJ Ship Management takes action to address this safety issue.

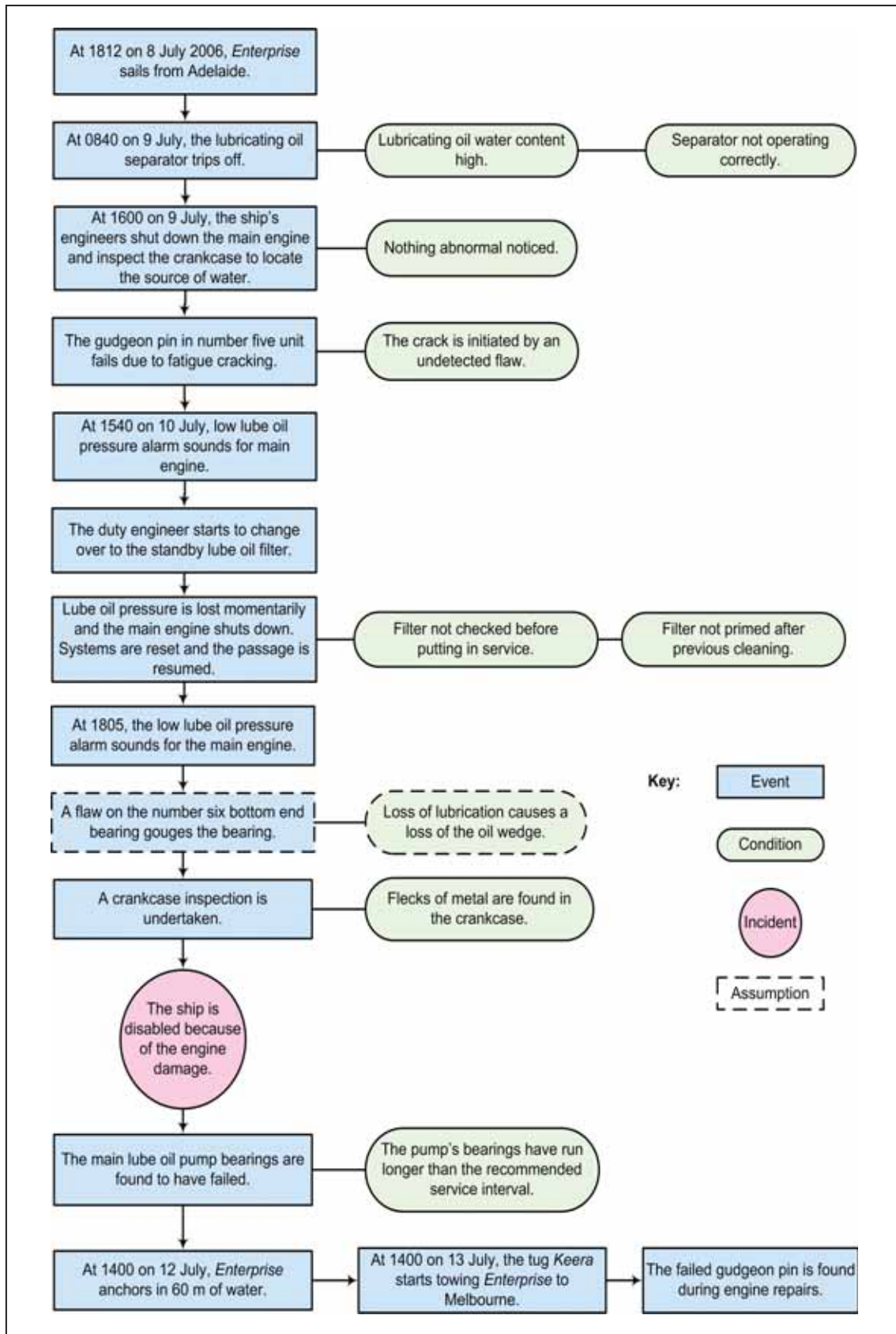
#### **MR20070029**

The shipboard procedures and practices for operating, maintaining and monitoring the K8E lubricating oil filter were inadequate. The standby filter was not checked to ensure that it was ready for use and the in-service K8E filter's condition was not adequately monitored.

The Australian Transport Safety Bureau recommends that AJ Ship Management takes action to address this safety issue.



# APPENDIX A: EVENTS AND CONDITIONS





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## APPENDIX B: SHIP INFORMATION

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### *Enterprise*

IMO Number	8321890
Call sign	V20L7
Flag	Antigua & Barbuda
Port of Registry	St John's
Classification society	Det Norske Veritas
Ship Type	Self-discharging bulk carrier
Builder	Mitsubishi Heavy Industries
Year built	1985
Owners	Zweite Belt Shipping
Ship managers	AJ Ship Management GmbH
Gross tonnage	6389
Net tonnage	2946
Deadweight (summer)	8709 tonnes
Summer draught	8.267 m
Length overall	113.01 m
Length between perpendiculars	106.03 m
Moulded breadth	20.21 m
Moulded depth	9.48 m
Engine	NKK SEMT-Pielstick 6PC2-5L-400
Total power	2582 kW
Crew	16



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## APPENDIX C: SOURCES AND SUBMISSIONS

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### Sources of information

AJ Ship Management  
Australian Maritime Safety Authority  
MAN Diesel Australia  
The master and crew of *Enterprise*  
Waterside Engineering

### References

NKK SEMT Pielstick service and operations manuals for the 6PC2-5L.

### Submissions

Under Part 4, Division 2 (Investigation Reports), Section 26 of the *Transport Safety Investigation Act 2003*, the Executive Director may provide a draft report, on a confidential basis, to any person whom the Executive Director considers appropriate. Section 26 (1) (a) of the Act allows a person receiving a draft report to make submissions to the Executive Director about the draft report.

The final draft of this report was sent to the Australian Maritime Safety Authority, the master, chief engineer and first engineer on board *Enterprise*, AJ Ship Management, ASP Ship Management and MAN Diesel Australia.

Submissions were received from ASP Ship Management, the chief engineer and first engineer on board *Enterprise* and MAN Diesel Australia. The submissions have been included and/or the text of the report was amended where appropriate.



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## APPENDIX D: MEDIA RELEASE

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### Undetected flaw disabled ship in Bass Strait

The ATSB has found that an undetected flaw, and the subsequent failure of a critical main engine component, led to the bulk carrier *Enterprise* being disabled in Bass Strait on 10 July 2006 and drifting for nearly three days.

The Australian Transport Safety Bureau investigation has found that a microscopic flaw led to the failure of a main engine gudgeon pin. The investigation also found that the engine manufacturer did not provide sufficient guidance for monitoring the fatigue life of gudgeon pins and that the planning and execution of maintenance on critical items of equipment was inadequate.

At about 1540 on 10 July 2006, while *Enterprise* was en route from Adelaide to Newcastle, the main engine low lubricating oil pressure alarm sounded, indicating that the main engine's lubricating oil filter was choked. While the duty engineer was changing over to the spare lubricating oil filter, oil pressure was lost, causing the engine to stop. The engine was restarted and the voyage was resumed.

At 1805, the alarm sounded again and the engineers stopped the engine. At 2000, after inspections had been undertaken, the chief engineer advised the master that there was probably damage to the engine's bearings and that the ship would need to be towed to the nearest port for repairs.

At 1400 on 13 July, *Enterprise* was taken in tow by the tug *Keera* and towed to Melbourne, where it berthed at 1900 on 15 July. During the engine repairs in Melbourne it was discovered that the gudgeon pin had failed.

The ATSB has made three safety recommendations with the aim of preventing further incidents of this type.







Independent investigation into the main engine failure  
on board the self discharging bulk carrier *Enterprise*  
in Bass Strait, 10 July 2006.