Report on the investigation of the machinery breakdown

and subsequent fire onboard

Maersk Doha

in Chesapeake Bay,

off Norfolk, Virginia, USA

2 October 2006

Marine Accident Investigation Branch
Carlton House
Carlton Place
Southampton
United Kingdom
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Extract from

The United Kingdom Merchant Shipping

(Accident Reporting and Investigation)

Regulations 2005 – Regulation 5:

"The sole objective of the investigation of an accident under the Merchant Shipping (Accident Reporting and Investigation) Regulations 2005 shall be the prevention of future accidents through the ascertainment of its causes and circumstances. It shall not be the purpose of an investigation to determine liability nor, except so far as is necessary to achieve its objective, to apportion blame."

NOTE

This report is not written with litigation in mind and, pursuant to Regulation 13(9) of the Merchant Shipping (Accident Reporting and Investigation) Regulations 2005, shall be inadmissible in any judicial proceedings whose purpose, or one of whose purposes is to attribute or apportion liability or blame.

The MAIB wishes to acknowledge the pivotal contribution made to this investigation by the US Coast Guard, and to thank them for their exemplary cooperation and support.

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GLOSSARY OF ABBREVIATIONS AND ACRONYMS

BA	-	Breathing Apparatus
CEC	-	Certificate of Equivalent Competency
CO_2	-	Carbon dioxide
EGE	-	Exhaust Gas Economiser
ISM	-	International Safety Management
kW	-	Kilowatts
MCA	-	Maritime and Coastguard Agency
MIRT	-	Marine Incident Response Team
°C	-	degrees Celsius
QCV	-	Quick Closure Valve
RAM	-	Random Access Memory
RPM	-	Revolutions per Minute
SMS	-	Safety Management System
STCW	-	International Convention on Standards of Training, Certification and Watchkeeping for Seafarers
TEU	-	Twenty foot Equivalent Unit
TIC	-	Thermal Imaging Camera
UPS	-	Uninterruptible Power Supply
USCG	-	United States Coast Guard
UTC	-	Universal Co-ordinated Time
VHF	-	Very High Frequency
ZMA	-	Zodiac Maritime Agencies

SYNOPSIS

The container vessel *Maersk Doha* sailed from Norfolk, Virginia, in the USA shortly after midnight on 2 October 2006. At 0030 an engine room alarm sounded indicating that pressure in the steam system was low. The crew investigated the cause of the alarm and discovered that steam was escaping from the auxiliary boiler air intake. They shut down the burner and opened the furnace door. Steam escaped, and when it had cleared they could see that the furnace tube was severely distorted and cracked.

There was some delay before the chief engineer was informed about the breakdown, and further delay before the problem was reported to the master on the bridge. Although the vessel could have anchored safely to investigate the situation, it was agreed that the main engine could continue to run at low power, and the vessel proceeded to sea.

An Exhaust Gas Economiser (EGE) was fitted in the funnel uptakes to generate steam from the waste heat contained in the main engine exhaust gases, using water circulated from the auxiliary boiler. At about 0200, a rapid rise in the temperature of the EGE was noticed and the chief engineer realised that there was a fire inside the EGE casing. The bridge was alerted at 0230 and the vessel's emergency alarm was activated. Radiant heat from the EGE ignited light fittings, cables and paint on bulkheads in the funnel uptakes, and the crew attempted to fight the fire with a water hose and a fire extinguisher. They were beaten back by the heat and smoke and the engine room was evacuated.

The crew were mustered and firefighters re-entered the funnel uptakes and began to cool the EGE casing using water hoses; they were withdrawn when their team leader grew concerned that the structure might collapse. The main engine room CO_2 gas smothering system was activated, but failed to discharge correctly and, in any case, would have had little effect on the fire. The fire was contained using water hoses to cool its boundaries and was finally extinguished, following advice received from the company head office, by drenching the EGE with water from the top of the funnel and through doors in the EGE casing.

The most likely cause of the fire was a malfunction of the auxiliary boiler control mechanism, which allowed the burner to keep firing with too little water in the boiler. This overheated the furnace, causing the distortion and cracking of the fire tube. As feed water was lost through the crack, the supply of water to the EGE failed, causing it to overheat. Soot deposits, which had accumulated within the EGE, then ignited. It is likely that temperatures in the EGE rose sufficiently high for hydrogen and iron fires to develop.

Inappropriate techniques were used to fight the fire initially, because the crew did not understand enough about the construction of the EGE or how to deal with the fire effectively. The vessel had an extensive Quality and Safety Management System, but it lacked sufficient detail to assist the crew in dealing with either the machinery breakdown, or the subsequent fire. Further problems became evident during the emergency when other equipment did not work correctly. The records of emergency drills and maintenance of machinery made it difficult for the vessel's managers to assess the quality of the work being carried out onboard. Neither these systems, nor the quality and technical audits carried out on the vessel, had been able to detect the underlying condition of equipment which subsequently failed during the emergency.

The crew, with the exception of the chief engineer, were from Eastern European countries. Despite meeting the requirements for gaining UK Certificates of Equivalent Competency and being able to use the working language of the ship, there was a tendency for the majority of the crew to revert to their shared native language. This had the effect of isolating the chief engineer and hindered his ability to understand and control the response to the emergency.

The management company undertook an investigation immediately after the accident and then promulgated to other managed vessels – in the form of safety and technical circulars – the lessons learned. Further measures were instigated to change emergency procedures and improve whole ship response.

In view of the action already taken, and in progress, no further recommendations are made as a result of this investigation.

Maersk Doha

SECTION 1 - FACTUAL INFORMATION

1.1 PARTICULARS OF *MAERSK DOHA* AND ACCIDENT

Vessel details

Registered owner	:	Selt Maritime
Manager(s)	:	Zodiac Maritime Agencies
Port of registry	:	London
IMO ship number	:	9103685
Flag	:	United Kingdom
Type	:	Container carrier, 4507 nominal TEU
Built	:	1996, Daewoo Shipbuilding and Marine Engineering, Korean Republic
Classification society	:	Lloyd's Register
Construction	:	Steel
Length overall	:	280.52m
Gross tonnage	:	51931 tonnes
Engine power and type	:	MAN B&W 8K90MCC producing 35500kW
Service speed	:	23 knots
Exhaust Gas Economiser	:	Aalborg AV6N finned tube economiser
Auxiliary Boiler	:	Aalborg AR-4C horizontal fire tube boiler

Accident details

Time and date	:	0230 local, 2 October 2006
Location of incident	:	36 57.66N 076 03.62W, 2 miles NW from Cape Henry, Chesapeake Bay
Persons on board	:	23 crew plus 1 pilot
Injuries/fatalities	:	None
Damage	:	Auxiliary boiler fire tube distorted and cracked. Exhaust gas economiser tubes melted and casing damaged. Radiant heat damage to engine room uptakes and funnel casing.

1.2 NARRATIVE

The information in this section is based on interviews with witnesses, records from onboard the vessel and reports from the management company. All times are local (UTC -6).

1.2.1 Background

Maersk Doha was trading on a regular route between the Far East and the east coast of the USA, via the Panama Canal. It had called at Miami and Savannah before reaching Norfolk, Virginia on 1 October 2006. Scheduled to sail late on the same evening, the vessel was due to arrive in Miami in the afternoon on 3 October, and thereafter sail to Mexico before returning to the Far East.

Problems with machinery started soon after the vessel sailed from Norfolk. The situation deteriorated as the vessel continued to sea, and shortly after the vessel passed the Chesapeake Bay Bridge and Tunnel, a fire was discovered in the funnel uptakes, above the engine room.

1.2.2 Work alongside and departure from Norfolk

Maersk Doha berthed at the Portsmouth Marine Terminal in Norfolk on 1 October, shutting down the main engine at 0630. Cargo operations began at 0800, discharging about 600 containers and loading a further 360. The vessel was scheduled to sail at 2100, but this was postponed during the early evening until midnight, to make alterations to the stowage plan.

The engineering staff took advantage of the time alongside to do maintenance and repairs on the engine while it was shut down. The auxiliary boiler was running throughout the time alongside, making steam to heat heavy fuel oil and for domestic purposes. Feed water from the auxiliary boiler was kept circulating through the Exhaust Gas Economiser (EGE) keeping it warm, ready for sailing.

At 2300, the bridge gave 1 hour's notice for sailing to the engine control room and the duty engineer began to prepare the main engine for sea. The third engineer was on duty and, as he was quite new to the vessel, the chief engineer supervised him, assisting where necessary. The main engine was prepared in accordance with the pre-sailing checklist, and control was passed to the bridge at 2354. During preparations, the third engineer had difficulty starting one of the generators and asked the second engineer to help rectify a problem with a control sensor. The second engineer had been off duty, but came down to the engine room to assist. He repaired the problem with the generator and was asked by the chief engineer to stay in the engine control room in addition to the duty engineers, as a precaution while the ship manoeuvred out of the port. With the chief engineer in the engine control room, the first engineer remained on standby in his cabin, in accordance with the company's normal procedure.

Two pilots were embarked, the first for the river passage and the second for the coastal phase of the outward transit. The first engine movement was made shortly after midnight at 0004 as the vessel came astern to leave the berth. Shortly afterwards, the chief engineer noticed a problem with the main engine reversing mechanism. Reversing the engine to go astern was achieved with pneumatic actuators altering the fuel injection timing for each individual cylinder. The actuator for the No. 7 cylinder had become stuck in the astern position, preventing that cylinder from operating and reducing the engine's power output. When the coastal pilot took over, the master informed him that the vessel was temporarily restricted to a maximum speed of 16 knots ahead. The master reported that he hoped this restriction would be removed during the passage, when the engineers had rectified a problem with the main engine.

1.2.3 Machinery layout

Maersk Doha normally ran on heavy fuel oil which needed to be heated by steam before it could be used in the main engine, generators or auxiliary boiler. Steam was generated either by the auxiliary boiler, or by hot exhaust gases from the main engine passing over the tubes of an EGE in the funnel uptakes. The system was designed to use the steam produced by the EGE while the vessel was sailing at full power, and for the auxiliary boiler to start automatically when engine power was reduced or the ship was alongside. The auxiliary boiler and EGE were linked together; feed water for the EGE was pumped from the auxiliary boiler and the steam made by the EGE returned to the auxiliary boiler steam space. A schematic diagram of this system is shown at **Figure 1**. The vessel also carried diesel oil to run the main engine, generators and auxiliary boiler, if heavy fuel could not be heated.

1.2.4 Auxiliary boiler failure

At 0030 an alarm in the machinery control room indicated that pressure in the steam system was low. This alarm was not considered uncommon and was normally a result of the auxiliary boiler failing to ignite, however there were no other alarms to indicate that this was the case. The third engineer continued to monitor steam pressure in the machinery control room, and saw that it was falling steadily. He was concerned that there was a serious problem and telephoned the first engineer for help.

The first, second and third engineers went to the boiler and generator compartment in the engine room to investigate the auxiliary boiler. The flame was still alight and the water level was reported to be in its normal position, but steam was escaping from the furnace air inlet. The third engineer shut down the fuel pump to extinguish the flame and opened the burner door to examine the furnace. More steam escaped through the open door and he was able to see that the furnace tube had bulged inwards and cracked, allowing steam to leak into the furnace[1].

Steam began to enter the surrounding compartment, and the noise of No.1 generator running nearby was distracting. The first engineer told the second engineer to use the Nos 2 and 3 generators on the other side of the engine room and shut down the No.1 generator. The second engineer anticipated that the steam to heat the heavy fuel might be lost, which could stop the generators from running, so he changed over the generator fuel supply to diesel oil. The lower viscosity diesel oil began to leak from joints in the generator fuel system, and the second engineer started repairing these leaks.

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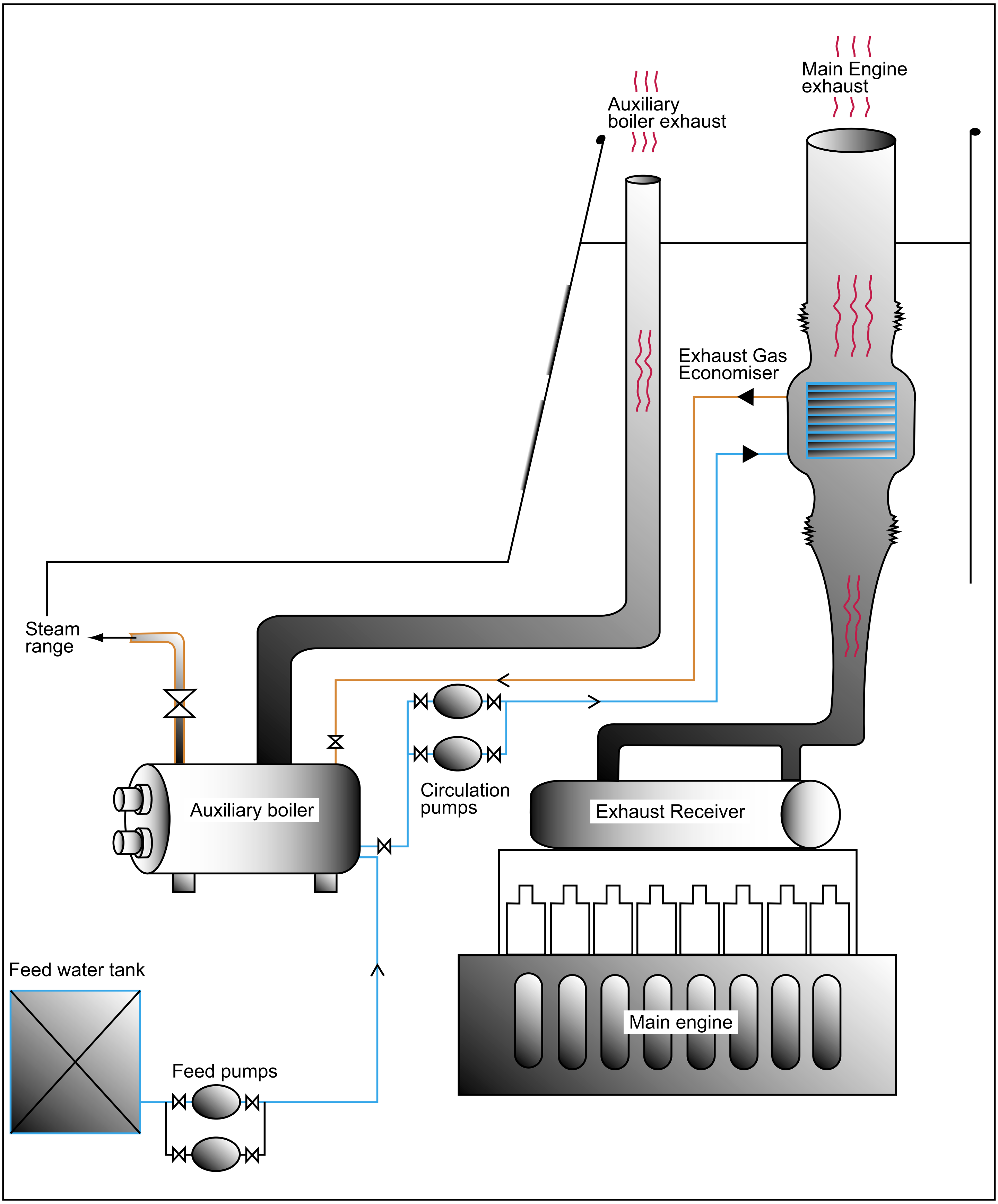
[1] The auxiliary boiler was made up of two horizontal tubes, with one mounted inside the other **Figure 8**. The inner tube formed the furnace with a flame burning at one end. Hot gases passed down the furnace tube to the other end of the boiler and reversed, travelling through a further two generating tube passes before leaving the boiler and exhausting through a funnel uptake. The furnace tube was mounted inside the water tube, so that the heat from the burner transferred outwards to the water and generated steam. The level of water in the outer tube was maintained at two thirds full, with the remaining third acting as a reservoir for the steam generated by the auxiliary boiler and that returning from the EGE.

Figure 1



Schematic diagram of the steam generation system

By 0050, the first and third engineers had returned to the engine control room to inform the chief engineer of the situation and study the auxiliary boiler operating manual, to work out a repair plan. The auxiliary boiler main steam valve was left open, allowing whatever steam was generated by the EGE to supply the steam system and heat the heavy fuel oil.

The EGE relied on the auxiliary boiler for its supply of feed water to generate steam, and a constant circulation of water was needed to stop the EGE from overheating. A second feed water pump was started to boost the flow of water into the auxiliary boiler. This was intended to help replace the feed water that was being lost as steam through the crack into the furnace and maintain a constant supply to the EGE. The feed water transfer pump[2] was also switched to automatic mode to ensure that a supply of feed water was available for the auxiliary boiler. Although there were two pumps available to circulate water through the EGE, the second pump had a faulty mechanical seal and could not be used.

The chief engineer noticed a low steam pressure alarm at 0120, but it can not be established whether this was the original, or a subsequent alarm. He telephoned the bridge to report the failure of the auxiliary boiler and requested the master to reduce speed, but did not explain why. The master asked if he should stop and anchor, or if it was possible to continue for the 1.5 to 2 hours needed to clear the port channel. The chief engineer advised that it was possible to continue, but at low speed. No speed limit was discussed or specified.

The weather was good and there was little traffic affecting the vessel. On the bridge, the pilot was aware that there was a machinery problem, but was not told what it was, or of any impact on sailing. He interpreted from the master's demeanour that the problem was relatively minor, but nevertheless offered to take the ship to a nearby anchorage and volunteered to stay onboard to help minimise any delay. This offer was declined and the vessel continued on passage.

The chief engineer continued discussing the options for repairing the auxiliary boiler with the first and third engineers. The master, in consultation with the chief engineer, increased engine speed steadily during this period. By 0136 the maximum manoeuvring speed of 70 rpm had been reached, giving over 16 knots.

1.2.5 Exhaust gas economiser overheating

Main engine revolutions remained at the maximum manoeuvring speed from 0136 to 0143 and the engine exhaust temperature increased. In the engine control room, the third engineer reported a rapid rise in the exhaust gas temperature at the outlet of the EGE, from 350 to over 600°C (beyond the sensor range) in less than 5 minutes. In response to concerns about the machinery, the bridge began to reduce engine speed at 0143 and by 0219, the engine was at dead slow ahead (20 rpm).

The chief engineer left the control room and climbed up the funnel uptakes to the EGE casing to investigate the cause of the high temperature alarms. The area around the EGE casing was very hot and he heard a hissing noise coming from inside. He realised that there was a fire inside the casing and returned, shouting to other crew. Parts of the casing were now red hot and in the surrounding compartment, cables and

[2] The feed water transfer pump moved water from storage tanks to the main feed tank where it was heated and de-aerated. It was normally operated manually as part of procedures to monitor feed water consumption. In the automatic mode, water was transferred as necessary to keep the main feed tank full.

light fittings were on fire and paint was beginning to blister, due to the radiant heat. The third engineer and a motorman attempted to attack the fire using portable extinguishers and a fire hose, but were beaten back by the heat and smoke.

The chief engineer reported the fire to the master on the bridge by telephone at 0230. The master instructed the officer of the watch to sound the ship's emergency alarm, and followed this with an announcement on the public address system, that there was a fire in the engine room and for crew to muster at their emergency stations. The master repeated his announcement and reinforced it by adding that it was not a drill. The pilot directed the helmsman to alter course towards a nearby anchorage outside the main channel.

The second engineer had initially dismissed the emergency alarm as a false alarm and continued to repair the fuel leaks on the generators. However, he was concerned about the additional announcements and returned to the engine room from the generator compartment. He saw smoke and burning debris falling down from the funnel uptakes near the main engine. Realising that he was the last person in the compartment, he quickly went to the engine control room. There he found the chief engineer and a maintenance worker struggling to open an escape door. The chief engineer ordered the second engineer to shut down the pump circulating feed water through the EGE but, thinking this action to be incorrect, the second engineer ignored the order, and left the pump running. All three men evacuated the control room using an escape ladder through a hatch in the deckhead.

1.2.6 Fire-fighting response

At 0234 the chief officer, in charge of the 6 man Emergency Team[3], reported to the master on the bridge that the team was mustered in the Fire Safety Control Centre, and that two people were dressed in fire-fighting suits and Breathing Apparatus (BA). The chief officer and first engineer discussed where to attack the fire and suggested to the master that they would enter the funnel uptake on "A deck" from the accommodation area. The master agreed with the plan and the main engine was stopped soon afterwards at 0239.

Shortly after the second engineer arrived at the muster station, the first engineer ordered him to start the emergency diesel generator. He started the engine but did not put it on load, numbers 2 and 3 main generators had been left running and were still supplying power. A short time later, the emergency generator shut down due to a high cooling water temperature, and could not be restarted.

Two firefighters wearing BA entered the funnel uptake through a door on "A deck" and attempted to cool the engine exhaust uptake and EGE casing using water from fire hoses. The chief officer stayed near the door to direct the firefighters. The radiant heat from the EGE casing grew, and sections of lagging started to fall off, exposing the steel structure glowing cherry red underneath. The chief officer did not know the precise construction of the EGE and grew increasingly concerned for the firefighters' safety. At 0248, he ordered the fire team to leave after a large section of lagging fell down, and reported to the bridge that the engine room had been evacuated. **Figure 2** taken after the accident shows the view the chief officer would have had from the doorway.

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[3] The Emergency Team was led by the chief officer and included the first engineer, two deck and two engine room ratings, in accordance with company guidance.

Figure 2

View of EGE and detached insulation

All personnel had mustered and been accounted for, and the chief engineer recommended to the master that the engine room CO_2 fire smothering system should be used. This was agreed and the first engineer and third officer activated the Quick Closure Valves (QCV) on the fuel and lubricating oil tanks in the engine room and shut the engine room fire dampers. At 0252, the remote operating valves in the Fire Safety Control Centre were opened to release CO_2 into the engine room. Ice was seen to form on the outside of the discharge pipe going into the engine room as the liquid expanded and cooled. Paintwork on this pipe cracked due to the low temperature.

The vessel was steered out of the channel towards a nearby anchorage, and the anchor was slipped just as CO_2 was being released at 0252.

1.2.7 Notification

Maersk Doha was safely anchored and the pilot left the bridge at 0300. He asked the master if he wanted him to inform the US Coast Guard and port authorities about the fire and request assistance. The master did not want assistance, but believed that the pilot had understood his request to inform the authorities. However, this was not understood clearly and the pilot left the ship believing that the master would inform the authorities. After leaving, the pilot monitored the VHF radio, listening for a report from the vessel, but grew concerned that he had heard nothing. At 0340 he reported the fire to his control tower, which in turn informed the port authorities and US Coast Guard.

The US Coast Guard responded at 0352, activating the local Marine Incident Response Team[4] (MIRT) soon after. Two tugs capable of fire-fighting, and each carrying a team of firefighters were despatched under the command of a captain from the Virginia Beach Fire Department.

1.2.8 Controlling the fire

Zodiac Maritime Agencies' head office in London was informed about the fire in the EGE by telephone and in an e-mail using a pre-arranged emergency reporting format. The chief engineer attempted to discuss the situation in more detail with technical staff by telephone. They found it difficult to understand what the chief engineer was describing, and asked him to write it down and send it by e-mail. Technical staff then spoke to the master and advised him that water must be sprayed through access doors in the EGE casing, directly onto the fire inside in order to extinguish it.

Although the QCVs had been closed to shut off fuel supplies in the engine room, No. 3 generator did not stop and kept supplying power to the vessel. The fire pumps were shut down when CO_2 was released and, at about 0400, the emergency fire pump was started to supply water to resume boundary cooling. It did not discharge any water and the first engineer went to the Ballast Control room to investigate the problem. He discovered that the pump had no suction pressure and would not prime. This was reported to the head office, who advised the crew to restore the pressure in the fire main using the main fire pumps in the engine room.

Personnel in the head office suspected that the CO_2 gas had not been properly released as the gas should have displaced the air and stopped No.3 generator. However, the first engineer and an A/B re-entered the engine room wearing BA. They went to the Control Room where they remotely started No.1 fire pump which restored a supply of water to the fire main.

Boundary cooling around the funnel casing had been resumed as the MIRT tugs arrived on scene at about 0600. The master declined the assistance of the fire teams because he believed that the crew had control of the situation, but allowed the fire captain and a marine chemist to come onboard and assist.

The fire captain brought a Thermal Imaging Camera (TIC) with him, which he used to show the boundary cooling team the hottest areas of the EGE casing. A fire hose was led up to the bridge roof and was used to put water into the main engine exhaust uptake at the top of the funnel. It was noted, using the TIC, that applying water to the EGE in this way increased the temperature of the fire, and when hoses were turned off to reduce the level of water in the engine room bilge, the fire began to cool. Shortly before sunrise (which was at 0701) the EGE casing was cool enough for the lower doors to be opened, and water was sprayed directly onto the tubes inside. As cooling progressed, the middle, and finally the upper EGE doors were opened and more water sprayed onto the tubes. The fire was finally declared extinguished at 1230. The marine chemist then tested the atmosphere in the engine room and certified it as safe to enter.

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[4] The role of the MIRT is to provide immediate assistance and support to any vessel in the immediate area, reporting to incident commanders ashore. It consists of members of the Coast Guard, Fire Department, US Navy and a number of local specialist companies.

1.3 DAMAGE TO BOILER SYSTEMS

Once the auxiliary boiler was cool enough to inspect, a bulge measuring about 1m long and extending about 0.6m into the furnace tube was discovered **Figure 3**. A circumferential crack, about 0.3m long was also found across the peak of the bulge. No defects were reported with the auxiliary boiler control mechanism or surveillance system.

The EGE was severely damaged with over half the tubes having melted **Figure 4**. Molten metal had solidified and gathered with ash and slag at the base of the exhaust trunking **Figure 5**. The EGE structure and casing were buckled by heat, which had also radiated to burn paintwork, cables, light fittings and fire detectors in the surrounding area.

Debris and water from the fire-fighting had fallen down the main engine exhaust trunk into the forward of the two turbochargers. Water gathering in the bilge had leaked through seals into the main engine oil tank underneath the sump. This contaminated oil, and the water from the fire-fighting efforts, were pumped into an empty ballast tank to preclude the possibility of subsequent pollution.

Figure 3

Auxiliary boiler - distorted furnace tube

Figure 4

Damaged tubes in EGE

Figure 5

Debris at base of EGE trunking

1.4 RECOVERY

1.4.1 Repair intentions

After the fire, the company's preferred option was for *Maersk Doha* to proceed to Miami, the next scheduled port. This would have simplified the logistic effort in getting repair teams and spare parts to the vessel and allow cargo operations to continue, albeit with some delay. In order to sail, the vessel needed to undertake the following work:

- Replace the defective emergency diesel generator
- Provide a method of heating the heavy fuel oil or bunker with additional diesel oil sufficient for the intended passage
- Remove damaged tubes from the EGE and make a path for the main exhaust gases
- Refill and re-commission the CO_2 fire-fighting system
- Remove salt water contamination from the main engine sump and crankcase
- Clean the main engine turbochargers
- Make safe damaged lighting and fire detection equipment in the funnel uptakes, and rig temporary lights.

A replacement furnace tube for the auxiliary boiler was ordered from a marine boiler repair company. While this was being manufactured, technical teams in the head office opted to conduct temporary repairs to the existing furnace tube. If these were successful, the plan was to fire the auxiliary boiler to generate sufficient steam for heating the heavy fuel oil and sail the ship to Miami. If they were unsuccessful, with only enough diesel fuel onboard for about 10 hours on passage, additional supplies would be purchased locally and all engines run on diesel oil for the 40 hour voyage down the coast.

1.4.2 Machinery repairs

Temporary repairs to the cracked furnace tube in the auxiliary boiler were made by a welder from the same company that was fabricating the new fire tube. He cut back the cracked area and welded the gap from both water and furnace sides. There was little that could be done to the distorted bulge in the furnace tube and it remained in the immediate path of the burner flame. It was inevitable that the flame would impinge on the bulge, which was coated with refractory cement to help protect it from overheating. After some difficulty in making the flame burn steadily, pressure in the auxiliary boiler was worked up slowly to between 3.5 and 4 Bar. The safety valves could not be adjusted to this lower working pressure and were reduced to their minimum settings of about 6.5 Bar.

Solidified metal was removed from the lower part of the EGE casing, and the damaged tubes cut back to create a path for the main engine exhaust gases **Figure 6**. Replacement parts for the EGE were ordered and repairs planned for a programmed maintenance period in the future.

The temporary repairs to the auxiliary boiler were discussed with senior management in Zodiac Maritime Agencies during the latter stages of the investigation. They claimed that these repairs had been done as an exercise, to see what could be achieved and to give the crew a target to work towards. They stated that their intention had been to assess the suitability of the repairs before deciding whether the vessel should sail. However, the two company superintendents and crew onboard the vessel immediately after the accident, regarded the temporary repairs as a major part of the work needed to get the vessel underway. There was no indication from either the superintendents, crew, or the welding contractor that they regarded the repairs as being a technical exercise.

Figure 6

Location of damaged tubes, cut away to create exhaust gas path

1.4.3 Response from other authorities

The US Coast Guard began a casualty investigation immediately after the fire was out, and a Port State Control inspection of the vessel was commenced on 3 October. During the inspection, electrical supplies were lost when the generators ran out of fuel. This was quickly followed by a second generator failure and it was found that the fuel service tanks had been emptied. In the attempts to restart the engines, the compressed air starting reserves were not isolated correctly and the air was used up. With no electricity, the air compressors could not be run to refill them. By 1000, the vessel had no lighting or other services and the Port State Control inspection was suspended. The emergency generator had overheated during the accident so a portable generator was loaded onto a barge which was then towed alongside *Maersk Doha* to provide power while services onboard were restored. Coast Guard casualty investigators attempted to review the sequence of alarms activated during the accident on the machinery control system, but found that these had been lost during the power failures. The automatic paper copy of the alarms was found to be illegible as the paper feed to the printer had jammed, causing it to overtype each alarm. The printer was reset by the Coast Guard investigators, who simply realigned the paper feed which allowed it to work satisfactorily.

The vessel's Classification Society was informed about the fire and the local surveyor attended the vessel during the afternoon of 2 October. He inspected the EGE and uptakes from the main deck upwards, and asked the ship to call him when they were ready for a final inspection. However, he was not made aware of the damage to the auxiliary boiler, which was reported to the Classification Society by the company's head office staff on 5 October. This information was then passed to the attending surveyor, who discussed the repair procedure by telephone with the superintendent onboard the vessel. Auxiliary boiler temporary repairs were completed on 6 October and the boiler was flashed later that evening. The surveyor examined the auxiliary boiler and the repair procedure documents during his next visit to the ship on 9 October. Although the work did not meet the manufacturer's or the classification society's standards for permanent repairs, they were considered acceptable as a temporary measure, with the boiler working at reduced pressure.

The company's head office made a request to the Maritime and Coastguard Agency (MCA), the vessel's flag state authority, to grant dispensation to the vessel for a single voyage to Miami without the fire detection system or full lighting working in the funnel uptakes. This was agreed on the understanding that the machinery spaces would be continuously manned and additional rounds made of the fire damaged areas. This dispensation was also subject to the inspection and approval of the Classification Society surveyor.

1.4.4 Sailing

Maersk Doha remained at anchor in Chesapeake Bay waiting for a temporary emergency generator to be delivered and fitted onboard. The replacement item was too large for any of the local vessels to handle, and could not be delivered until a larger vessel arrived from a nearby port and the weather improved. The replacement furnace tube for the auxiliary boiler arrived during this period and was fitted while the vessel was still at anchor. *Maersk Doha* finally sailed on 16 October, 2 weeks after the accident.

1.5 CREW

All the crew were employees of Zodiac Maritime Agencies (ZMA), recruited via ZMA's manning agents in Romania, Ukraine and an independent agent in the Republic of Korea. The complement of *Maersk Doha* was in excess of that required by the vessel's Safe Manning Certificate, and all relevant crew held appropriate qualifications in accordance with the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) with UK Certificates of Equivalent Competency (CECs).

The working language of the ship was English. Records of the hours of work and rest had only been completed up to the end of September, but showed a consistent pattern for all the crew involved in the accident having received adequate rest.

The master was Russian and had worked for ZMA for nearly 10 years, having been promoted to master in 2000. He joined the ship for a second contract on 29 August. His spoken English was a very good standard.

The chief engineer was from the Republic of Korea and had been working at sea since 1978, having been chief engineer for the last 12 years. He moved to ZMA in 2003, and had started this latest contract nearly 5 months before the accident on 10 May. The master and other members of the engineering department occasionally found it difficult to understand his spoken English, and this was supported during interviews when both MAIB and US Coast Guard investigators found his language extremely difficult to understand.

The first and second engineers had both completed cadetships with ZMA and remained with the company thereafter. They were Romanian and Ukrainian respectively, and both were sailing on their first contracts in the rank. The first engineer joined the ship on 18 May with the second engineer joining on 13 June. The third engineer was Romanian and had joined the ship on 27 September having spent 2 years working for ZMA.

The electrical engineer was also Ukrainian and was on his 4th contract with ZMA, having joined the company in 2003. He was responsible for all the electrical equipment onboard, including machinery control systems.

1.6 MAIN MACHINERY AND STEAM SYSTEM

1.6.1 General description

Maersk Doha was fitted with a 2-stroke, slow speed, turbocharged diesel engine developing 35,500kW. The service speed of 23 knots was achieved at 98rpm, and the maximum manoeuvring speed was 70rpm, giving a speed of 16 knots. The engine could be started and run on either heavy fuel or diesel oil. Heavy fuel had to be heated by the steam system to reduce its viscosity so that it could be pumped through the fuel injectors and burnt efficiently.

Main engine exhaust gases were collected in an exhaust gas receiver which was connected to the turbochargers. Exhaust gases then went into the uptake trunking which was connected via flexible bellows to the EGE casing. Exhaust gases passed over water tubes inside the EGE casing, transferring some of the waste heat from the engine exhaust into the circulating water system to generate steam.

The auxiliary boiler had a horizontal furnace tube mounted inside a water drum to generate steam at 7.5 Bar pressure, a general view is shown at **Figure 7**. Fired by heavy fuel or diesel oil, the fuel was mixed with air and ignited to create a single flame. Hot gases passed down the furnace tube to the other end of the boiler and reversed, travelling through a further two generating tube passes before leaving the boiler and exhausting through a funnel uptake. The furnace tube and generating passes were immersed in the boiler water drum as illustrated in **Figure 8**, with the normal water level above the top of the tubes.

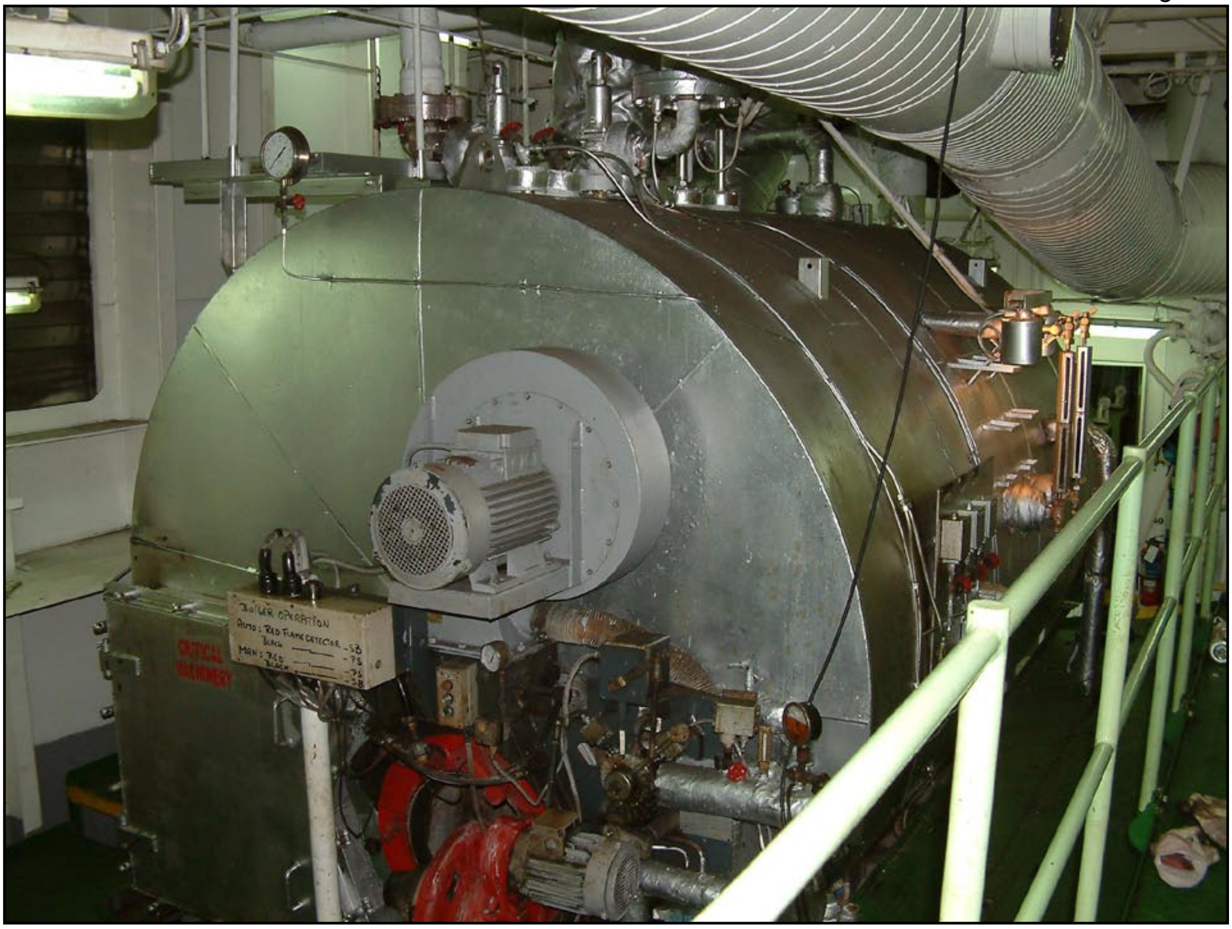
The auxiliary boiler could be operated automatically, with local controls interfaced with the main machinery control system. Automatic controls started the auxiliary boiler when the pressure in the vessel's steam system was below 5.8 Bar and stopped it when the pressure rose above 7.4 Bar. The low pressure alarm was activated at 4 Bar. Feed quality water from storage tanks was transferred to the main feed tank by an automatic or manually controlled pump. Two feed pumps (one operating and one standby) took suction from the main feed tank and fed the boiler via a variable flow control valve. The boiler control system sensed the level of water in the boiler and altered the position of the feed control valve accordingly, to maintain the correct level of water depending on steam demand. Sensors were fitted to turn off the burner flame if the water level fell too low and prevent the boiler from overheating.

Two circulation pumps (one operating and one standby) took suction from the bottom of the auxiliary boiler water drum and pumped water, at a temperature of 90°C, up to the water header at the top of the EGE. Water flowing down through the header into the EGE tubes was heated by main engine exhaust gases and the steam generated passed back down to the auxiliary boiler. Steam from both the auxiliary boiler and EGE mixed, and went into the ship's steam range through the auxiliary boiler main steam stop valve.

The vessel was fitted with three 1870kW electrical generators capable of running on heavy fuel or diesel oil. Cooling water from these engines could be used to provide enough waste heat for domestic services, but was not capable of heating heavy fuel. The 250kW emergency diesel generator was fitted on the starboard side of the main deck in the accommodation area. This was a water cooled engine with its own air cooled radiator so that it was not dependent on sea water cooling.

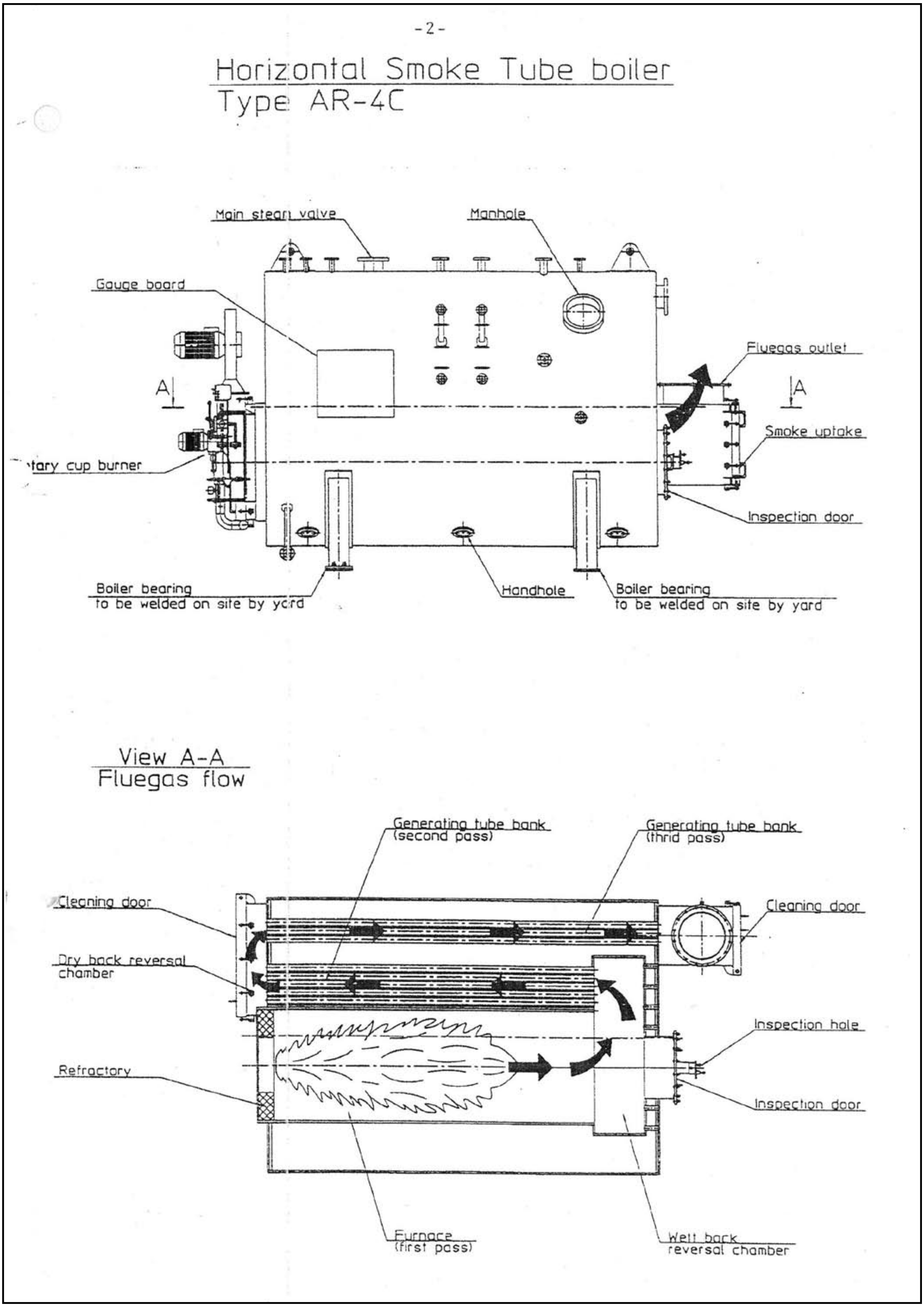
Maersk Doha was fitted with two bilge, fire and general service pumps in the engine room. No. 1 pump was normally configured for fire-fighting. The emergency fire pump was fitted in the after part of the ship, beneath No. 8 hold.

Figure 7



Auxiliary boiler

Figure 8



Schematic diagram of auxiliary boiler taken from manufacturer's manual, onboard vessel

1.6.2 Exhaust gas economiser soot cleaning

Soot and other products of combustion from the main engine exhaust would accumulate on the EGE tubes, reducing heat transfer efficiency and increasing the risk of fire. Three separate soot cleaning systems were fitted to the EGE:

- Ultrasonic
- Compressed air soot blowers
- Water washing nozzles

The ultrasonic system used high frequency sounds to induce vibrations in the EGE to prevent soot deposits from accumulating on the tubes, and operated automatically every 30 minutes. Soot blowers connected to the engine air starting system were designed to operate both automatically and manually, and rotated to blast compressed air over the tubes, dislodging the soot which passed out of the EGE with the engine exhaust gases. The water washing system was connected to the salt water fire main, delivering water to clean the tubes through a number of fixed nozzles at the top of the EGE, as shown at **Figure 9**. Any salt deposits were then removed from the EGE by rinsing the tubes with fresh water. Drains underneath the EGE could be opened to collect the dirty water in a holding tank.

Figure 9

Water washing pipework and nozzles at the top of the EGE

1.6.3 Plant maintenance and background

A technical circular was sent to all container vessels managed by ZMA on 22 May 2003 reporting a serious EGE fire on another vessel managed by the company. The fire was caused by accumulation of soot on the EGE tubes and advice was given on cleaning EGEs and how to fight such a fire effectively. This is summarised below:

- *Clean gas side of EGE at least once every month with a large volume of sea water, followed by rinsing with fresh water*
- *Soot blowing system to be used regularly when at sea*
- *In the event of a fire, attack with a huge volume of water directly onto the EGE tubes, either through a fixed system where fitted, or by removing casing access covers.*

The content of this circular was not transferred into the Quality and Safety Management system after its initial distribution. A copy of the circular is at **Annex A**.

Maersk Doha reported an unusually high feed water consumption between 17 and 19 August 2005, due to leaks in the EGE tubes. The affected tubes were isolated by plugging and welding each end shut.

A manufacturer's service engineer was called to assist with problems on the auxiliary boiler in Shanghai on 31 October 2005. The service engineer rectified a number of defects with the boiler, including:

- Steam pressure controller settings incorrect, such that boiler would not automatically start or stop.
- Automatic burner start / stop function not working
- Threshold settings for machinery control alarms outside normal limits

The service engineer also recommended that the diffuser and burner assembly be cleaned while the vessel was at sea, and that leaks on the furnace door and water level gauge be repaired. The service report also advised that the steam pressure switch should be renewed.

Two sections of EGE tubes were replaced during a dry docking period from 21 February to 4 March 2006. A number of Classification Society surveys on the boiler system were also completed:

- EGE examined internally and safety valves tested
- Auxiliary boiler internally examined on water and gas sides. External boiler and mountings visually inspected. Steam valves inspected. Safety trips and safety valves functionally tested.
- Confirmatory surveys of both outer feed and circulation water pumps. (Inner pumps last surveyed in 2004).

Maintenance records showed that the gas side of the EGE should be washed monthly and had last been water washed on 31 August 2006. There were several conflicting accounts of how frequently the soot blowers were operated, ranging from automatically 2 to 3 times per day, reducing to once per week. The soot blower control panel had a note written in marker pen, saying "do not run in auto", supporting the consensus from the crew that soot blowers were operated manually. The last recorded time that soot was blown was on 30 September 2006, as the vessel was travelling up the coast towards Norfolk.

Higher than normal feed water consumption of $11m^3$ was recorded in the 24 hours preceding this accident. No other periods of unusually high usage were evident from September's feed water tank records.

The emergency diesel generator was last run and put on load on 10 September 2006. The emergency fire pump was tested monthly, with the most recent test on 16 September 2006 being recorded as "Good working condition".

1.6.4 Machinery Controls

The vessel was fitted with an automated alarm and monitoring system covering principal machinery systems, allowing Unmanned Machinery Space Operation. The parameters monitored for the auxiliary boiler, EGE and related systems are listed at **Annex B**.

All safety devices, alarms and machinery trips were required to be tested monthly, but the maintenance system did not include a list of what had to be tested. Records showed monthly entries reporting that equipment had been tested, but gave no indication of what had been checked or how it had been done. Repairing control system defects reported by other engineering staff was regarded as the principal means of fault detection and was given priority over other maintenance. Other checks were made by measuring parameters with a digital multimeter on running equipment. Temperature probes could not be tested independently due to a lack of test equipment onboard, and were checked by swapping similar probes and watching if the measured output changed significantly.

Operating parameters were monitored by the system and could be shown in a number of different formats on a display screen in the engine control room. Parameters which exceeded preset values activated an audible alarm. Details of each alarm were shown on the display screen and a paper copy automatically printed as a permanent record.

When the US Coast Guard began their investigation on 3 October, the printer was found misaligned on its mounting and unable to feed paper from the storage bin. This had caused the printer to write over previous alarms, with the last legible entry being made on 23 September. Alarms were also saved in the system's Random Access Memory (RAM). This was reliant on the electrical supply being available and was backed up by an Uninterruptible Power Supply (UPS). Despite this, the RAM alarm data was lost following the two power failures that occurred on 3 October.

1.7 FIXED CO_2 FIRE SMOTHERING SYSTEM

Maersk Doha was fitted with a fixed CO_2 gas system to smother fires in the engine room and cargo holds. Consisting of 224 CO_2 cylinders, of 45kg capacity each, the system could be operated in four modes to fight engine room fires as follows:

- 224 cylinders to all engine room spaces
- 7 cylinders to generator and auxiliary boiler room
- 7 cylinders to generators 2 and 3
- 10 cylinders to the purifier room

Two hundred and twenty three cylinders were required to meet regulatory requirements for drenching the engine room. A separate set of distribution valves could be opened and CO_2 cylinder valves manually released to drench cargo holds.

A pilot system remotely operated the valves on each 45kg CO_2 cylinder to release gas into a manifold. Four, pilot system operated, distribution valves on the manifold allowed gas to be diverted to the whole engine room, or sections of it as described above. The pilot system was driven by two 2kg CO_2 cylinders fitted in each of the eight remote operating cabinets, one to open the correct number of cylinder release valves and the other to open the distribution valve. The location and function of each cabinet are described in detail in Table 1 below:

Location of remote operating cabinets	**Discharge systems controlled by each cabinet**
Fire Safety Control Centre	Engine room No. 1 Generator and auxiliary boiler room Nos 2 and 3 Generator room Purifier room
CO_2 room	Engine room No. 1 Generator and auxiliary room Nos 2 and 3 Generator room Purifier room Cargo holds
Generator and auxiliary boiler room	Generator and auxiliary boiler room only
No.s 2 and 3 Generator room	Nos 2 and 3 Generator room only
Purifier room	Purifier room only
Paint room	Paint room only
Scavenge chamber	Scavenge chamber only

Table 1-1 CO_2 remote operating system

The pilot operating system relied wholly on pilot gas pressure, with no contribution from the main CO_2 charge to operate the release valve mechanism. Release valves could be operated manually, by striking a lever on the valve body. Movement of this lever also indicated when the valve had been operated, either manually or by the pilot system.

Pipework distributed CO_2 gas throughout the engine room, terminating in nozzle fittings beneath deckheads to allow the dense gas to fall under gravity and displace air, smothering the fire. The highest of these nozzles were on “A deck”, with two being fitted just below the EGE, outside the casing in the funnel uptake space.

The system was last serviced and inspected on 1 December 2005. The contents of each cylinder were checked using a liquid level indicator, and cylinder valves were visually inspected. The release systems were also visually inspected, but not tested.

1.7.1 Re-commissioning

After the fire, a local contractor was employed to refill the CO_2 cylinders and re-commission the system. The crew had disconnected the cylinders from the system in preparation before the contractor arrived at the vessel, and he began to check their contents by weighing each cylinder in turn. Four cylinders were found to be empty and another two slightly undercharged. The remaining 218 cylinders were still full and were refitted to the vessel.

The contractor investigated the pilot operating system to determine why fewer cylinders had discharged than expected. He tested all four pilot systems; locally in the CO_2 room and remotely in the Fire Safety Control Centre. The systems operated the release and distribution valves correctly in all eight permutations. The same two pilot cylinders were used throughout the tests, indicating that there were no significant leaks in the pilot system.

1.8 SHIP MANAGEMENT

ZMA provide all ship management functions for *Maersk Doha* and are the International Safety Management (ISM) Code registered ‘company’ on behalf of the vessel’s owners.

Management operations are largely paperless and based on an extensive computer system. The Safety Management System (SMS), quality management, maintenance and other performance measuring systems are integrated with electronic messaging in one system. Managed vessels are linked to the company system in the head office.

1.8.1 Quality and Safety Systems

The computer system provides both SMS and quality management functions onboard, including the following sections:

- Quality, Policy and Procedures Manuals
- Standing Instructions
- Safety Manual and Emergency Operating Procedures
- SOLAS Training Manual
- Fire Training Manual

All managed vessels are audited annually by the company to ensure compliance with procedures. In addition, the managers target vessels considered to be in need of additional supervision, auditing them as frequently as each port visit, if necessary. *Maersk Doha* had not been the subject of any additional targeted audits prior to the accident.

All accidents and incidents are investigated onboard and also by superintendents from the head office if considered necessary. Fleet and Technical circulars are published to managed vessels to describe any incidents and identify the lessons to be learnt from them. Circulars remain extant for a year, after which they are either deleted or included into the next routine amendment of the Safety and Quality management system. Monthly safety bulletins are published, summarising safety performance and identifying any areas of concern.

An intermediate audit for the International Safety Management (ISM) and Ship Security Codes was conducted by the MCA onboard *Maersk Doha* from 13-15 May 2006. Observations of engine room watchkeeping and bunkering were included in the audit and a minor non conformance concerning radar equipment was raised. The audit made an observation that an incorrect version of a navigational audit form was being used, and noted that the crew could not get sufficient hours of rest on part of the Far East phase of the voyage.

1.8.2 Company emergency procedures

ZMA's head office provides emergency response to company vessels, giving advice, support and arranging any external assistance or repairs required. Vessels submit emergency messages in prearranged formats to streamline reporting and follow these up with telephone calls to the Designated Person Ashore (Operations Manager) or the Deputy Designated Person Ashore (Technical Director).

Emergency operating procedures and fire-fighting guidance were available onboard the vessel in the computer based Quality and Safety Management System, but these were not consulted during the accident. A paper file of emergency operating procedures made by the vessel's previous owners was found by investigators in the engine control room. This contained a number of useful procedures, including a flow chart describing how to detect and respond to an EGE soot fire, but none of the crew were aware of it.

1.8.3 Engine room fire drills

Engine room fire drills were required to be completed monthly. All were recorded as having taken place, with the last one before the accident being held on 19 August 2006. The results of every fire drill were listed as being 'good', but there was no record of what type of drill was practised. The Safety Manual suggested practising different types of drill, and the Fire Training Manual described a number of different techniques, but the detail and complexity of the drill were left to the crew to decide.

1.8.4 Crew management and recruitment

ZMA's crew are largely taken from Eastern European countries such as Russia, Ukraine, Turkey, Bulgaria and Romania. A small number of senior officers are recruited from the Republic of Korea. The company has a policy of mixing crew from different nationalities provided that they have the appropriate qualifications. These are verified and UK CECs obtained where necessary. New recruits are required to undertake a Marlins English Language test and achieve a score of greater than 90% for captain and chief officer and at least 80% for chief engineer. Applicants for senior positions then have a telephone interview, followed by 5 days of training and evaluation at the ZMA head office.

Crew are evaluated every 2 months by the master, and additionally during visits by superintendents, auditors and port captains. Evaluations include an English language assessment scored between 1 and 5. The scoring definitions are shown in the Crewing Manual Circular reproduced at **Annex C**. Any scores of 5 are considered as a recommendation not to re-employ the individual. The majority of the chief engineer's language assessments were given a score of 3, corresponding with the definition:

> "*Can communicate satisfactorily about everyday topics with a restricted range of language. Able to understand native speakers of English, talking at measured pace with some re-phrasing and repetition. Comprehension is likely to fail under pressure".* [Sic]

The Crewing Manual Circular at **Annex C** also states that chief engineers are required to achieve a score of 2 in their evaluation reports.

1.8.5 Technical

A planned maintenance system was used on all company managed vessels, based on running hours and periodic inspection. It was not part of the Classification Society's *approved Machinery Planned Maintenance Scheme*[5]. Tasks and periodicities were determined by technical staff in ZMA's head office, derived from manufacturer's recommendations and other operating experience. A list of maintenance tasks was accessed via computer workstations onboard the vessel. A description of each task was given with the date due and a very high level outline of what work was required. More detailed descriptions were available in the manufacturer's operating and maintenance manuals held onboard in the engine control room. Staff in ZMA's head office routinely checked maintenance records against the date it fell due, and any deviations were brought to the attention of senior management. There were no such deviations for *Maersk Doha*, and all maintenance was recorded as being complete.

The chief engineer was responsible for ensuring maintenance was completed properly and was required to update the system as tasks were finished. On *Maersk Doha*, in line with normal company practice, the first engineer controlled day to day maintenance. This was achieved by posting up a list of all tasks due each month in the engine control room, and arranging when each job would be done with other engineering staff. Staff would tick each task off when it was complete and the computer system would then be updated with the date each item was completed. This had to be approved and sent back to the head office by either the chief engineer or master. Crew members acknowledged that much of their time was taken up repairing defects and that this work had to take priority over other planned maintenance. The chief engineer held a *Certificate of Authorisation* from the Classification Society under the *approved Chief Engineer Scheme*[6]. He was authorised to undertake surveys on main propulsion and auxiliary machinery, but not boilers or pressure vessels.

Technical audits by company superintendents took place every 2 to 3 months. In addition to checking the condition of machinery and quality of maintenance, the superintendent also compiled a work list of additional tasks for the crew. Progress against this list was recorded in a weekly message from the ship to the main office, along with another list of additional, unscheduled work items. The last superintendent's report for *Maersk Doha* was dated 14 Jun 06 and did not identify any of the deficiencies exposed during this accident.

The requirement for repairs or other external assistance was decided by the company's technical department ashore, based on reports from the vessel. Crew were only authorised to arrange their own repairs in extreme circumstances.

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[5] Approved Machinery Planned Maintenance Schemes are an optional service from the Classification Society, designed to help vessel operators improve reliability of machinery.

[6] Approved Chief engineer Scheme authorises named individuals to undertake certain machinery surveys on behalf of the Classification Society.

1.9 SOOT AND HYDROGEN FIRES

Production of soot is inevitable in a modern diesel engine of the type fitted in *Maersk Doha*. At exhaust temperatures in the expected range of 240 -270°C at the EGE inlet, soot deposits are expected to burn at high engine powers and this is part of the design to help keep the EGE clean. However, soot deposits will accumulate if soot blowers are not operated regularly. If soot becomes “wet” from lubrication oil carried over from the engine, it is more likely to burn. The flash point of dry soot is in the range of 300-400°C[7], however this can be reduced to 150°C if the soot is wet and, in extreme conditions, to as little as 120°C.

EGE designs try to maximise the surface area of the tubes to improve the amount of heat recovered from the engine exhaust gases. In *Maersk Doha*, the tubes were fitted with fins, with each set butting up to its neighbour creating a grille effect for the exhaust gases to pass through. Safe operation relied on both the soot deposits being cleaned away and water being continually circulated through the tubes to prevent heat building up to reach the soot flash point. The EGE could be operated without water circulating through the tubes, but only if it was clear of soot deposits. In good EGE design, prevention of soot accumulation is aided by designing the EGE so as to create a high exhaust gas velocity across the finned tubes to carry the soot away. This can be difficult to achieve where, as in *Maersk Doha*, there is a 90^{o} bend in the exhaust trunk directly before the EGE inlet. In such situations, the gas flow can be disrupted, leading to localised areas where soot builds up. To prevent soot accumulating, the EGE manufacturers recommend regular soot blowing at least 2 to 3 times each day, and consider water washing to be more a part of periodic maintenance. However, the frequency of both soot blowing and water washing should be based on regular inspection of the EGE to assess its cleanliness. Cleaning routines should then be adjusted accordingly.

Small soot fires are common, particularly when the engine is running at low power and its combustion is less efficient. Temperatures in the EGE will increase if water circulation fails or a fire is able to develop in areas of heavy soot concentration. This can reach the point at which the fin and tube material weakens and fails, causing water to leak out. Research by the engine manufacturer[7] indicates that if temperatures reach 1000°C water molecules can dissociate into hydrogen and oxygen causing what may be referred to as a hydrogen fire. This not only provides the fire with fuel, but also the oxygen needed for it to burn and the fire can become self sustaining. At temperatures above 1100°C, the iron in the tube materials can be oxidised in a reaction that produces heat, it may also react with steam in a different process which also generates heat. Collectively, these two reactions are known as iron fires. Such self sustaining fires can only be extinguished by applying copious amounts of water to cool the fire below 1000°C. A lesser amount of water, which allows the temperature to be sustained, may provide additional fuel for the fire. Extracts from this research have been reproduced at **Annex D**.

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[7] Open source MAN B&W Technical paper P280-04-04 dated 22 April 2004
http://www.manbw.com/article_004063.html.

SECTION 2 - ANALYSIS

2.1 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.

2.2 CIRCUMSTANCES LEADING TO THE FIRE

2.2.1 Auxiliary boiler failure

The distortion and subsequent cracking of the furnace tube in the auxiliary boiler was due to sustained overheating. This could have been either as a result of firing the boiler with a low water level, or because the water drum was fouled with heavy scaling or from gross oil contamination. No evidence was found of scaling or oil contamination and it is therefore most likely that the boiler was operated with a low water level. Feed water records for September show consistent consumption, suggesting that the boiler was not operated with a low water level until just before the accident.

The auxiliary boiler local control system should have detected a low water level, alerted operators, and shut down the burner to safeguard the boiler. It is unlikely that if an alarm had activated, it would have been ignored, and in light of the service agent's report and considering the methods used to maintain the control system, it is more probable that a malfunction occurred in this system which allowed the water level to drop and keep the burner firing.

When the low pressure steam alarm was first investigated, the water level in the auxiliary boiler was reported to be in the correct position. If the control system had failed and the water level fallen, it is unlikely that it would have then increased and recovered to the normal position automatically; so either the observation was incorrect, or the feed water level was restored manually. If the water level had been restored manually, the damage to the boiler from overheating should have been evident and might have been disregarded in the hope that the boiler would continue to work.

The severe distortion to the furnace tube would have taken time to occur and as it grew under steam pressure, the material would have been further weakened from localised heating where the flame impinged on it. The feed controller might have been able to make up for the feed water losses when the crack first formed, but as it increased in size, losses would rise and steam would have been lost through the furnace tube, activating the low pressure alarm.

The lack of any machinery alarm records and inability of the crew to describe how the auxiliary boiler failed, prevents the exact sequence of events from being established. However, all the circumstances described above are attributable to ineffective operational and maintenance routines.

2.2.2 EGE fire

The crew must have been conscious that feed water was being lost from the auxiliary boiler to consider boosting the water supply by starting the second feed pump. The water which circulated through the EGE was pumped from the bottom of the auxiliary boiler and, hence, it was essential that there was sufficient reserve of water available there to prevent the EGE from overheating. Steam returning from the EGE to the auxiliary boiler would have been able to leak through the furnace tube as well, therefore increasing the loss of water. If the level of water in the auxiliary boiler was allowed to fall too low, it would be highly likely that water circulation through the EGE would be lost. Then the only positive way of preventing it from overheating would have been to stop the main engine, removing the main source of heat.

Soot deposits would have accumulated in the EGE since the last time soot was blown on 30 September, and this accumulation would have been exacerbated when the main engine was being operated at low power during the entry and departure from Norfolk. This would have helped to create the conditions needed for a soot fire, and the risk of a fire starting would be greatly increased if the EGE began to overheat through loss of water circulation.

There was a 50 minute delay between the first low pressure steam alarm at 0030 and the bridge being informed about the auxiliary boiler failure at 0120. Feed water was being lost throughout this period, and with the engine working up in power, exhaust gas temperatures and consequently temperatures within the EGE, would have increased. Although the master suggested stopping and anchoring the vessel, the chief engineer did not consider this necessary, if the engine was kept at low power. The phrase 'low power' was not defined, and engine revolutions increased during the next 16 minutes. They remained at maximum manoeuvring speed for a further 7 minutes as the vessel headed to sea. The EGE outlet temperature was seen to rise rapidly above normal operating temperatures and was soon beyond the maximum sensor range of 600°C. A reduction in engine speed was begun at 0143 in response to concerns about the machinery. Engine speed continued to be reduced over the next half an hour, but the condition of the EGE was not investigated until 0219, by which time the fire was well established. By keeping the main engine running after the auxiliary boiler had failed, the crew had placed machinery and the safety of the vessel at greater risk.

2.2.3 Fire-fighting technique

Maersk Doha was fitted with an EGE water washing system fed from the fire main. This would have been ideal to attack the soot fire in its early stages, and was the method described in the technical circular on dealing with EGE fires, included at **Annex A**. The crew did not consider using this system, and the first fire-fighting attempts were with a portable extinguisher and a hose on cables and light fittings set alight by radiant heat from the EGE casing. This response had no effect on the conditions developing within the EGE; the main engine was still running and the fire would have continued to grow.

The first attack was soon beaten back and, shortly afterwards, the engine room was evacuated. Firefighters wearing BA were dressed and entered the funnel uptakes beneath the EGE casing commendably quickly. They began to cool the outer casing, and surrounding compartment, but had no effect on the seat of the fire as it was inside the EGE structure. As lagging fell from the outer casing it gave the appearance that the structure was collapsing. The chief officer, in charge of the team, did not know how the EGE was constructed, so his concern that his firefighters were in severe danger was understandable.

The fire-fighting team would have benefited from more detailed technical information about the fire and how it had started. Those fighting the fire did not understand enough about what they were dealing with to be effective.

The chief officer ordered the firefighters to withdraw, and having abandoned the engine room a second time, the remaining options were limited. A re-entry from another point could be attempted or the fixed CO_2 drench system used. The latter option might appear more sensible with the fire developing seriously, to help prevent it from spreading, but its seat was inside the steel EGE casing and despite the efforts so far, this had not been reached. Had the crew understood how the fire was burning and considered their options further, they would have realised that CO_2 stood little chance of working because of the following factors:

- The highest CO_2 discharge nozzles were below the EGE casing and the dense gas would have sunk down into the rest of the engine room.
- Even if the nozzles had been above the EGE, the gas would have been unable to penetrate the casing into the tube area to have any effect on the fire.
- Finally, with the outer casing glowing cherry red, its temperature can be estimated as being in the range of 700 – 900°C. It is reasonable to expect that the temperature at the seat of the fire was higher and quite possibly above 1000°C at which water can dissociate into hydrogen and oxygen. If this was the case, CO_2 drenching would have had no effect as the oxygen being produced from the water present would have made the fire self sustaining.

The decision to release CO_2 was taken and personnel were accounted for, fuel and oil QCVs operated and ventilation for the compartment closed down. The first engineer and third officer activated the CO_2 system and opened the cabinet in the Fire Safety Control Centre containing the engine room release valves. These were operated and it was assumed that CO_2 had been released successfully. Ice was seen to form on the discharge pipework leading to the engine room, but because of the risk of CO_2 leaking into the cylinder storage compartment, the operators did not enter further than the doorway and did not check the position of the release valves on the cylinders.

The main fire pump had been shut down and fire-fighting efforts stopped while the CO_2 was activated. The emergency fire pump was started but could not be made to draw suction. After efforts to prime the pump were unsuccessful, the vessel contacted technical staff in ZMA for advice. They were doubtful about the decision to use the CO_2 drench, and with the main generator still running were concerned about its effectiveness. ZMA's technical staff advised the crew to re-enter the engine room, start the main fire pump and then get water directly onto the EGE tubes through casing doors. With the EGE casing too hot to approach, boundary cooling was resumed and hoses put down the funnel to get water onto the EGE tubes.

The situation was now becoming more controlled, and when the MIRT vessels arrived on scene the master declined the assistance of the fire teams as he was concerned that they might use techniques which could cause additional damage. The fire captain was able to assist, and advised where to direct boundary cooling efforts using his thermal imaging camera. It was at this time that temperatures were seen to increase with the application of water onto the EGE tubes, and it was only later, when fire-fighting was stopped to reduce the level of water in the bilge, that temperatures fell. This observation strongly suggests that hydrogen and iron fires had developed. Continued boundary cooling was sufficient to contain the fire in the EGE casing and its immediate vicinity. Once it was cool enough to remove EGE casing doors, water was sprayed onto the tubes and the fire was extinguished.

2.2.4 CO_2 system failure

After the fire, it was anticipated that all the CO_2 cylinders would need refilling. The first engineer and third officer were confident that they had operated the correct control valves because they had seen ice forming on the discharge pipe, indicating that gas was flowing into the engine room. The contractor employed to refill the cylinders began by measuring their contents by weight. It was soon discovered that only 4 out of the expected 224 cylinders were empty, with a further 2 being undercharged.

There are two possible reasons why so few cylinders were released: either the wrong controls were operated, or the remote system had failed to work correctly. There were four separate control cabinets in the Fire Safety Control Centre, one for the whole engine room and three for smaller compartments within the engine spaces. Each of the 3 smaller compartments required 7 or 10 gas cylinders to be released, and it would have been possible to select the wrong cabinet and cause fewer cylinders to be released. If this had been the case, the gas would have passed through a much smaller sized delivery pipe to the relevant compartment, causing the pipe to freeze. Ice was only reported as forming on the large main engine room delivery pipe, and its presence was confirmed by the paintwork cracking as it froze. There was no damage to any of the other three pipes, indicating that the correct control cabinet had been used.

The contractor employed to refill the cylinders tested the operating system using fully charged pilot cylinders in each cabinet. It was confirmed that operating each cabinet activated the corresponding discharge valve and the correct number of cylinder release valves. The only remaining explanation for the system not working correctly was that the pilot operating cylinders contained too little CO_2 to activate more than the first 4 of the 224 cylinder release valves.

The system had been inspected 10 months previously and so was approaching its next annual inspection. The previous inspection had used visual methods, with cylinder contents checked by indicators to show the level of liquid inside each cylinder. No functional tests had been undertaken. It is possible that the previous inspection failed to detect that the pilot cylinders were undercharged, but more likely that their contents leaked gradually during the following 10 months. Neither the first engineer nor the third officer checked the pilot cylinder contents indicators before operating the control valves. If they had, and these had shown that the pilot cylinders were empty, they could have operated the system from the remote station in the CO_2 room or fitted cylinders from another cabinet in the fire safety control room.

2.3 ENGINEERING DEPARTMENT

2.3.1 Reaction to auxiliary boiler breakdown

A low steam pressure alarm on the machinery control system was not considered uncommon by the crew and was normally caused when the burner of the auxiliary boiler failed to ignite. No other alarms were seen to support this being the case and the third engineer's concern grew as he monitored the steadily reducing steam pressure. The auxiliary boiler was crucial to the operation of the main propulsion plant because not only did it generate steam to heat the heavy fuel oil, but also functioned as the steam receiver for the EGE. With the burner shut down, the only steam available was that being generated by the EGE.

While the reduction of heavy fuel heating was certainly significant, the fuel would have taken some time to cool and the main engine could have been run on unheated diesel oil if necessary. More importantly, but perhaps less apparent, was that the EGE relied on the auxiliary boiler for its source of feed water. The EGE circulation pumps would soon empty the boiler, as feed water leaked away and steam continued to flow. The auxiliary boiler main steam valve was left open to allow the remaining steam to continue heating the heavy fuel. With the system operated in this manner, it was likely that water circulation through the EGE would fail and, if that happened, exhaust gases from the main engine would have caused it to overheat.

2.3.2 Advice given to the bridge

After considerable delay, the bridge was told about the auxiliary boiler failure. The master asked if he should anchor the vessel and stop the engine, or if it was possible to carry on to clear port limits. The chief engineer agreed that they could continue at low power before stopping to inspect the auxiliary boiler and make repairs. This was almost an hour after the first low pressure steam alarm and the master neither asked for, nor was given, further explanation. It is unlikely that, if he had understood the real significance of the breakdown, he would then have increased speed to full manoeuvring power.

Having just advised the master that it was possible to continue at low power, the chief engineer remained in the engine control room as engine speed increased. No power limitations had been agreed, and the only way of judging the success of the plan was by monitoring the EGE exhaust outlet temperature. The bridge began to reduce engine power at 0143, probably in response to concerns about the EGE becoming too hot, yet the master appeared relaxed, unaware of the growing risk of major damage and fire.

2.3.3 Maintenance

Apart from the failure of the auxiliary boiler, there were other examples where equipment did not work properly that were attributable to ineffective maintenance or equipment checks:

- Standby EGE circulation pump mechanical seal
- Automatic operation of soot blowers
- Fuel tank Quick Closure Valves
- CO_2 drench pilot operating system
- Emergency diesel generator overheating
- Emergency fire pump suction

The maintenance system recorded that checks and planned maintenance were complete on all these items, and that there were no defects. While it is always possible for equipment not to work in an emergency, so many serious defects should not occur during the same incident. Neither the maintenance system nor any of the technical audits detected these latent defects, so the effectiveness of these systems must be questioned.

It is also significant that the failure of the automatic alarm printout had not been acted on. This had been illegible for over a week, yet had either not been seen or its failure was accepted. US Coast Guard investigators were quick to identify the cause, and the printer soon worked properly. A history of recent alarms was held electronically and could be displayed on the screen. This facility was in regular use, but the data was lost after the accident during the subsequent generator failures, indicating that the uninterruptible power supply to the system did not work properly. That such comparatively simple problems could be overlooked gives little confidence in either the standard of watchkeeping or maintenance onboard the vessel.

Although automatic safety control and trip devices were required to be tested each month, no record could be found listing which equipment was to be tested. It was evident during interviews that crew understood the requirements to test safety trips, but without a checklist to refer to, it was quite possible that some equipment could be overlooked. Similarly, there was no means of recording that individual tests had been completed in the maintenance records, preventing management from identifying any shortcomings.

2.4 EMERGENCY PROCEDURES

2.4.1 Emergency response

There was slow escalation in the level of response from the initial machinery breakdown through to the fire being discovered. It is arguable, given the crucial role of the auxiliary boiler to the main propulsion plant, that its failure was an emergency in its own right, yet it was 15 minutes after the auxiliary boiler was shut down before the chief engineer was informed. The situation deteriorated as feed water was lost, but even after the chief engineer became involved, the response continued in the same manner. Reactions only escalated once the fire in the EGE was discovered, by which time it was well established and serious damage was inevitable.

The third engineer was new to the vessel and the first and second engineers were sailing on their first contract in the rank. Their experience was limited in comparison with the chief engineer, and they should have informed him immediately of the problem they were experiencing, in accordance with company instructions. This would have given the chief engineer more time to understand what was happening and consider what action to take. The bridge should have then been given a fuller explanation of the problem, and particularly its implications.

The remainder of the crew reacted swiftly to the emergency alarm and master's announcement. Firefighters were dressed and available quickly, however, although they provided some boundary cooling to the EGE casing, they failed to attack the seat of the fire because they did not understand where or how it had started. Several members of the engineering staff should have been in a position to describe how the breakdown had led to the fire starting, but this information was not shared or used effectively.

Further technical problems were evident when the emergency diesel generator shut down. The water side of the cooling system was not full and the engine had overheated. Its failure could have been disastrous, however, the combination of neither the CO_2 drench nor the fuel quick closure valves working properly allowed No. 3 main generator to keep running and supplying power to the vessel. Other complications caused by the failure of the emergency fire pump sea suction delayed cooling efforts, but once the fire main was restored no further problems were encountered.

2.4.2 Guidance available

Guidance for fire-fighting techniques and emergency operating procedures was provided in the computer based Quality and Safety Management System. Checklists referred to a wide range of topics, but did not include enough detail to be of help with either the machinery breakdown or the fire in the EGE.

A paper file of emergency operating procedures, produced by the vessel's previous owners, had been kept in the engine control room. This was readily accessible and contained relevant information in a simple format. However, it had not been endorsed by ZMA, and the crew were not familiar with its contents.

Useful guidance on EGE soot fires had been published in a ZMA technical circular in 2003, but the copy kept onboard *Maersk Doha* was only found after the incident. ZMA's policy was for such circulars to either expire or be incorporated into other documentation at the next annual update of the Quality and Safety Management System. This circular was not incorporated into an update, and company managers interpreted it as having expired.

2.4.3 Deck and engineering department interaction

The delay in engineering staff informing the bridge about the auxiliary boiler failure, and the lack of explanation given to the master, suggests limited interaction between deck and engineering departments. The master accepted the chief engineer's report without further questioning. The subsequent increase in speed shows that either the chief engineer had failed to explain the implications of the breakdown, or the master had not understood its significance. Even though the chief engineer was concerned about the EGE overheating, he allowed engine speed to increase in response to the master's orders. Poor communication and understanding between the master and chief engineer placed the vessel at greater risk, for little benefit.

Limited interaction was further evident while fighting the fire, when the chief officer remained in charge of the emergency team despite not fully understanding the nature of the fire or construction of the EGE. The first engineer, who was also part of the emergency team, could have provided more advice to the chief officer or taken charge of the team as suggested in company guidance.

2.4.4 Engine room fire drills

Engine room fire drills were required to be practised monthly, but the nature and detail of the drills were left to the crew. With this arrangement, it is extremely difficult to ensure that the quality and variety of drills are maintained, and it is too easy for crew to become complacent in their ability. The records did not show what type of drill had been completed, preventing managers from measuring progress and performance effectively.

2.5 ACCEPTANCE OF RISK

2.5.1 Machinery breakdown

The auxiliary boiler was crucial to the safe operation of the propulsion plant, and its failure presented the risks of losing heavy fuel heating and overheating the EGE. The crew mitigated the loss of fuel heating by keeping the auxiliary boiler main steam valve open and relying on the steam produced by the EGE to heat the fuel. Unfortunately this action also increased the risk of losing water circulation through the EGE and of it then overheating. Given that the engine had been operating at low power for some hours, soot accumulation in the EGE was inevitable, and there was a substantial risk of overheating resulting in a soot fire.

These risks could have been reduced by slowing the main engine, or avoided altogether if the vessel had been taken to anchor and the main engine stopped. Engineering staff chose to accept these risks for 50 minutes before even reporting the initial boiler failure to the bridge. There were no navigational reasons to prevent the vessel from stopping, but as the master did not appreciate the significance of the problem, he inadvertently added to the risk of fire by increasing speed.

Tolerance of the technical risks caused by the auxiliary boiler failure, combined with the decision to increase speed, caused the EGE to overheat and start the fire. No other factors have been identified that would influence operating with such risks, other than the crew's collective determination to clear port limits and get to sea with minimal delay.

2.5.2 Machinery repairs

It was soon apparent that the EGE was damaged beyond repair. There was not enough diesel fuel onboard for the intended voyage and, unless more was purchased locally, the auxiliary boiler would be needed to generate steam to heat the heavy fuel oil. ZMA's technical staff had quickly placed an order for a replacement furnace tube from a boiler repair company, but this was going to take some time to fabricate and deliver to *Maersk Doha*. In the interim, a welder from the same repair company was sent to the vessel to make temporary repairs to the existing, damaged furnace tube. The crack was welded up, but little could be done to the distorted material in the path of the burner flame, other than attempt to protect it with a layer of refractory cement. Firing the auxiliary boiler in this condition would put greater stresses on the furnace tube, potentially causing it to collapse. Despite the obvious danger, and with the crew noticeably concerned, the auxiliary boiler was flashed and worked up to about 3.5 Bar pressure. This not only put the safety of those working in the engine room at risk, but also increased the chance of causing more serious machinery damage.

Debris from the EGE was cut away and removed to create a path for the main engine exhaust gases. Once a path had been made, the rest of the collapsed tubes were left in place at the bottom of the EGE casing, such that vibration or movement of the ship at sea could have caused debris to come away and fall back down the exhaust trunk towards the main engine turbochargers. Flexible bellows in the exhaust trunking perforated by burning material were also left, pending evaluation of the extent of the inevitable exhaust leakage before considering any repairs.

2.5.3 Sailing intentions

The senior management at ZMA reportedly regarded the temporary repairs to the auxiliary boiler as an "exercise" to see what could be achieved and provide the crew a target to work towards. These goals were not shared with those onboard the vessel. Company superintendents and crew onboard, gave investigators a consistent message that, once temporary repairs were complete and the heavy fuel brought back up to temperature, the intention was for *Maersk Doha* to sail to Miami. If the superintendents and crew onboard had known that the temporary repairs were unlikely to be relied on in practice, they could have avoided the additional risks caused by flashing the auxiliary boiler.

Ultimately, delays in delivering a replacement emergency diesel generator allowed the replacement fire tube to be fitted, making any need to operate the auxiliary boiler with temporary repairs unnecessary.

2.6 CREWING ISSUES

2.6.1 Communication

The working language onboard *Maersk Doha* was English and the crew had achieved the necessary standard to obtain UK CECs. All the officers apart from the chief engineer came from Eastern European countries and shared a common language which was observed to be in regular use. This had the effect of isolating the chief engineer even in normal circumstances, but would have been exacerbated during the emergency, making it substantially harder for him to understand and control what was happening.

Despite exceeding the required Marlins test score, the chief engineer had only achieved scores of 3 for the language section in the majority of his evaluation reports, less than the score of 2 required by ZMA's crewing manual. The definition for a score of 3 includes the statement that, '*comprehension is likely to fail under pressur*e'. It is apparent from the chief engineer's actions throughout the accident that he had difficulty understanding what was being reported to him and that language barriers hindered his command of the situation.

Investigators interviewing the chief engineer found it extremely difficult to frame questions that he understood, and to interpret his answers. This amply illustrated the communication problems that would have been present during the emergency.

2.6.2 Leadership

The chief engineer had worked at sea for many years and had experience of a wide variety of vessels. He was well liked by other crew and was regarded as a very hard working man with a gentle demeanour. As the machinery breakdown developed, he reported to the bridge but did little else to direct his subordinates. By the time the first and third engineers told the chief engineer about the auxiliary boiler failure, the EGE was already at risk, yet the chief engineer accepted their initial actions and allowed them to continue. This decision demonstrated a lack of appreciation of the overall machinery state and an unwillingness to make an unpopular decision that would cause the vessel to be delayed.

The chief engineer gave at least one order that was disregarded by his subordinates. Ordering the second engineer to stop the circulation pumps can be interpreted in two ways depending on the time it was given relative to the development of the fire. In the early stages it would have stopped the circulation and caused the EGE to overheat. In the latter stages at higher temperatures, water from the circulation pumps could add fuel to the fire. Either way, the fact that the second engineer disregarded the order, and was allowed to do so by the chief engineer, showed a lack of leadership and discipline.

Fire-fighting was led by the chief officer and first engineer, with the chief engineer's role limited to advising on the release of CO_2 gas into the engine room. After discussions with staff in ZMA's head office, the chief engineer's influence was further reduced, partly through language difficulties but also because the effectiveness of his decision to release CO_2 was doubted.

2.7 QUALITY AND SAFETY MANAGEMENT

2.7.1 Crew reaction

Members of the crew involved in this accident had worked for ZMA for a number of years, and had in two cases completed cadetships with the company. It is therefore reasonable to consider that their working practices were influenced by company policies and practices. Of greatest concern must be their willingness to accept the risks posed by the machinery failures and delay reporting these problems to the chief engineer. This was compounded by poor communication and understanding at all levels within the ship, such that the initial problem grew to the point where serious damage was inevitable. Weaknesses in maintenance, emergency drills and procedures were soon exposed, presenting a very different condition to that indicated by the vessel's records. This underlying condition had not been detected by any of the internal or external audits conducted on the vessel.

2.7.2 Emergency operating procedures

Crew response throughout this accident placed the vessel at increasing risk until a severe fire was inevitable. No emergency response procedures were referred to, and those that were available were either unofficial or lacking in detail. Thereafter, poorly considered fire-fighting techniques failed to attack the fire and worsened the vessel's condition. Only the intervention of technical staff in ZMA's head office helped the crew to regain control and extinguish the fire. This demonstrates a clear need for emergency operating procedures to be properly endorsed; sufficiently detailed to be useful; and drilled regularly to gain familiarity.

2.7.3 Maintenance system

The maintenance management system provided high level guidance on what each task included. Crew completing the maintenance records only needed to record the date work was completed and, in some cases, add a brief comment. This system was reliant on the individuals' interpretation of what was required and gave third parties limited appreciation of the validity of the report or the scope of work undertaken. A more detailed work specification and qualitative recording would have assisted managers and auditors in identifying problem areas.

Significant equipment defects were exposed during the emergency, even though the corresponding records showed all maintenance to be complete. It was evident that the crew's main workload was to repair defects, and planned maintenance had a lower priority. Although the vessel appeared to be well maintained, there were too many shortcomings revealed by the accident for this to be the case.

2.8 FATIGUE

It is unlikely, given the pattern of hours shown in the record of hours of work and rest, that fatigue was a contributory factor in this accident.

SECTION 3 - CONCLUSIONS

3.1 SAFETY ISSUES

Safety issues directly contributing to the accident which have resulted in actions being taken:

1. The most likely cause of the distortion and cracking of the auxiliary boiler furnace tube was sustained overheating due to operation with a low water level. This was most likely to have been caused by a malfunction of the boiler's automatic controls. [2.2.1]
2. Loss of feed water in the auxiliary boiler led to failure of the water circulation through the EGE, causing its temperature to increase. [2.2.2]
3. Periods at low engine speeds during entry and exit from Norfolk caused soot deposits to accumulate in the EGE. These had not been removed by cleaning. The soot deposits ignited as the EGE overheated. [2.2.2]
4. The crew placed machinery and the safety of the vessel at increasing risk by keeping the main engine running. [2.2.2]
5. Delays in reporting the problem to the bridge and lack of advice given to the master exacerbated the problems caused by the initial machinery breakdown. [2.3.2]
6. The risks posed by the failure of the auxiliary boiler could have been avoided by taking *Maersk Doha* to anchor and stopping the main engine. [2.5.1]

3.2 OTHER SAFETY ISSUES

Other safety issues identified during the investigation also leading to actions being taken:

1. Unsuitable techniques were used to attack the fire because crew did not understand the construction of the EGE or the processes involved in high temperature soot fires. [2.2.3]
2. Failure of several items of machinery and safety equipment during the emergency illustrated that maintenance and equipment checks had not been effective. [2.3.3]
3. The combination of the CO_2 drench and fuel quick closure valves not functioning correctly, allowed No. 3 main generator to continue providing power when the emergency diesel generator overheated. [2.4.1]
4. Emergency operating procedures and fire-fighting techniques in the Quality and Safety Management System did not contain sufficient detail for them to have been helpful in tackling this accident. Other documents held onboard did contain useful guidance and emergency procedures, but these had not been endorsed by the company. [2.4.2]
5. Conduct of engine room fire drills had allowed crew to become complacent in their ability. The records of drills completed by the crew did not allow managers to assess crew performance effectively. [2.4.4]

6. Difficulties with language and poor communication contributed to a lack of leadership in controlling the machinery breakdown and fighting the fire. [2.6.1]
7. Significant defects exposed during the emergency were not detected by internal and external audits of the vessel. [2.7.1]
8. Emergency operating procedures should be properly endorsed, sufficiently detailed to be useful and drilled regularly to gain familiarity. [2.7.2]

SECTION 4 - ACTION TAKEN (OR TO BE TAKEN)

Zodiac Maritime Agencies

ZMA undertook an investigation immediately after the accident and has also conducted a detailed review of its Quality Management System. As a result, they report that they have taken, or are in the process of taking the following actions:

a) The circumstances of the accident and lessons learnt from the company's investigation were published to other managed vessels in safety and technical circulars which describe the actions to be taken when dealing with serious soot fires, **Annex E**.

b) Emergency procedures have been reviewed to improve whole ship response, with specific actions to:
   a. Review the functions and composition of emergency teams
   b. Define the roles and duties of personnel in emergency teams by their post held onboard, to standardise procedures across the managed fleet
   c. Provide simpler and more logical cross references between the Safety, Fire Training and SOLAS Safety Training Manuals
   d. Revisit an earlier company project investigating emergency drills to help improve the quality and relevance of shipboard drills
   e. Make alterations to emergency reporting formats requiring vessels to include more detailed information on the circumstances of any accident.

c) A process to discuss and review the use of contingency anchorages in emergency situations has been included in navigational audits.

d) Planned Maintenance System records for lifesaving apparatus and fire-fighting equipment have been enhanced to include additional details on what tests and maintenance have been completed.

In addition, ZMA has taken the actions listed below, to improve safety performance in vessels managed by the company:

a) A chief engineer was recruited to join the Quality and Safety department in September 2006. The role of this post includes ensuring the correct operation and maintenance of safety equipment during audits of vessels managed by the company.

b) A trial of the MCA sponsored Human Element Assessment Tool for ships (HEAT-S)[8] is scheduled to begin in March 2007.

US Coast Guard

The USCG fined the vessel for failing to report the accident in accordance with local regulations and issued a subpoena for information needed to carry on with its investigation.

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[8] Extract from the MCA website regarding the HEAT project, "*HEAT is a questionnaire-based tool, developed as a proactive method of improving industry consideration of the human element. It is designed to complement the ISM Code, by evaluating the capability of those responsible for safety management to address the human element. HEAT goes further than ISM by encouraging continuous improvement rather than superficial compliance, and is intended to assess where human element risks are not being adequately addressed*".

SECTION 5 - RECOMMENDATIONS

In view of the action already taken, and in progress, no further recommendations are made as a result of this investigation.

Marine Accident Investigation Branch
July 2007

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