



Bundesstelle für Seeunfalluntersuchung
Federal Bureau of Maritime Casualty Investigation
Federal Higher Authority subordinated to the Ministry
of Transport and Digital Infrastructure

Summary Investigation Report 20/17

Incident

**Failure of the main engine with subsequent
emergency anchor manoeuvre on the bulk carrier
MV CAPE LEONIDAS on 17 January 2017 in the area
of Kolmar on the River Elbe**

6 November 2019

This summary report within the meaning of Article 27(5) of the Law to improve safety of shipping by investigating marine casualties and other incidents (Maritime Safety Investigation Law – SUG) is a simplified report pursuant to the second sentence of Article 14(1) of Directive 2009/18/EC of the European Parliament and of the Council of 23 April 2009 establishing the fundamental principles governing the investigation of accidents in the maritime transport sector.

The investigation was carried out in accordance with the aforementioned legislative framework, which provides that its sole objective is to prevent future accidents. This investigation does not serve to ascertain fault, liability or claims (Article 9(2) SUG).

This report should not be used in court proceedings or proceedings of the Maritime Board. Reference is made to Article 34(4) SUG.

The German text shall prevail in the interpretation of this investigation report.

Issued by:
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1 FACTUAL INFORMATION

1.1 Photograph of the ship



Figure 1: MV CAPE LEONIDAS

1.2 Ship particulars

Name of ship:	CAPE LEONIDAS
Type of ship:	Bulk carrier
Flag:	Marshall Islands
Port of registry:	Majuro
IMO number:	9488865
Call sign:	V7VL6
Owner:	Empire Bulkers Ltd., Elliniko, Greece
Year built:	2010
Shipyard/Yard number:	Daehan Shipbuilding Co Ltd., Hwawon, South Korea (Haenam Shipyard)/1021
Classification society:	Lloyd's Register
Length overall:	292.00 m
Breadth overall:	45.06 m
Draught (max.):	18.20 m
Gross tonnage:	93,565
Deadweight:	180,149 t
Engine rating:	18,660 kW
Main engine:	Doosan – MAN-B&W 6S70MC-C
(Service) Speed:	15.4 kts
Hull material:	Steel
Minimum safe manning:	20

1.3 Voyage particulars

Port of departure:	Narvik, Norway
Port of call:	Hamburg
Type of voyage:	Merchant shipping/international
Cargo information:	Iron ore
Manning:	20
Draught at time of accident:	15.10 m
Pilot on board:	Yes

1.4 Marine casualty or incident information

Type of event:	Incident
Date, time:	17/01/2017, 0507
Location:	River Elbe, Kolmar area
Latitude/Longitude:	ϕ 53°44.1'N λ 009°26.2'E
Ship operation and voyage segment:	Estuary trading on the River Elbe; proceeding toward Hamburg
Consequences:	No injuries or environmental damage. Loss of the starboard anchor; no other damage to the ship

Extract from Navigational Chart 'THE ELBE FROM KRAUTSAND TO SCHULAU', BSH¹ No 47 (INT 1454)

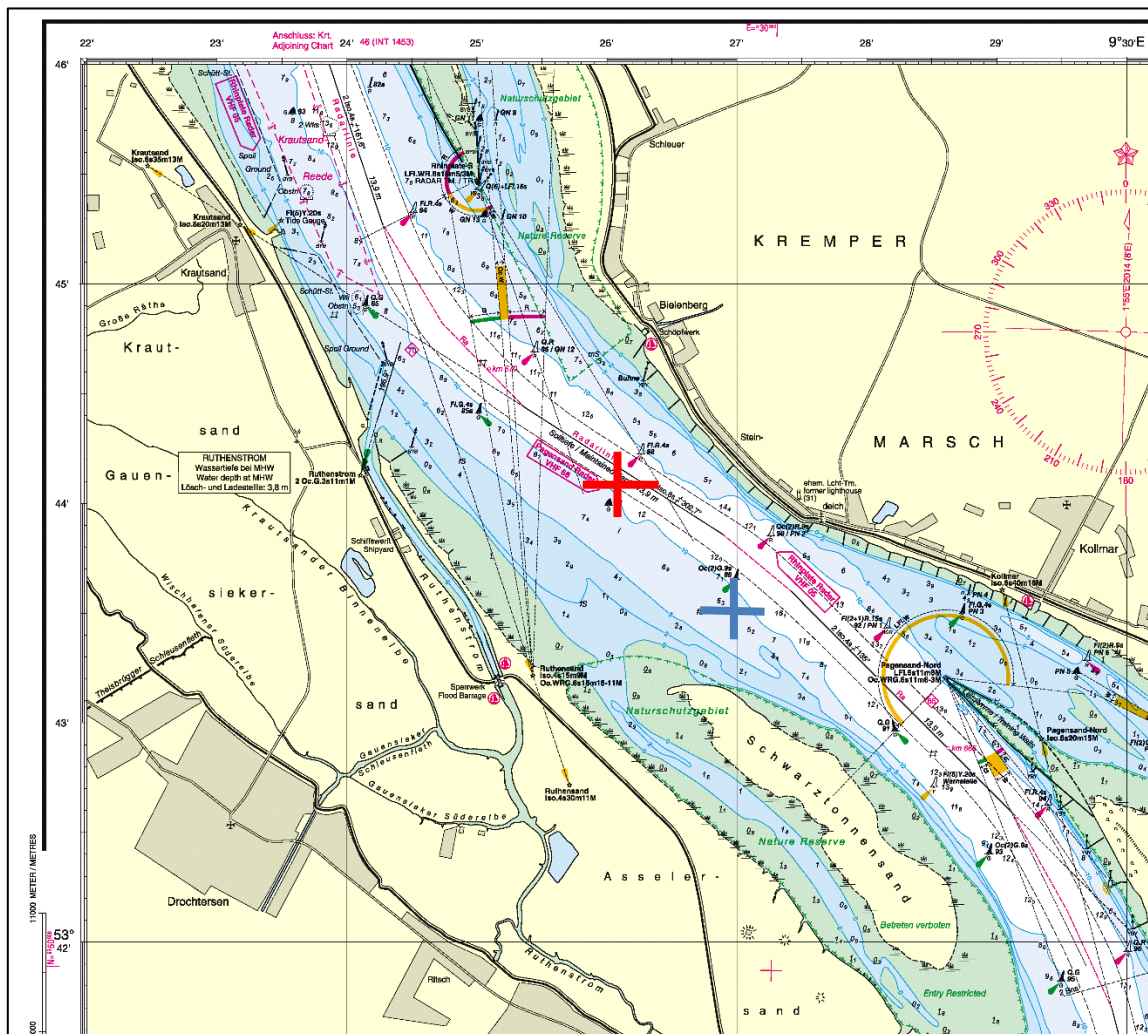


Figure 2: Scene of the incident

0507: Emergency anchor manoeuvre in the fairway
1017: Anchorage south-west of buoy 89
(after being towed in the meantime; waiting there for the next high tide)

¹ BSH: Federal Maritime and Hydrographic Agency.

2 COURSE OF THE INCIDENT AND FINDINGS OF THE INVESTIGATION

2.1 Course of the incident

The bulk carrier CAPE LEONIDAS (flag: Marshall Islands) was fully laden with ore and started to experience problems with her main engine at about **0330²** on **17 January 2017**. At this point, the ship was sailing toward Hamburg in calm winter weather on the River Elbe. She was manned by a pilot who was assisted in his advisory activities by a radar pilot at Vessel Traffic Service (VTS) Elbe. Due to her draught, the CAPE LEONIDAS was reliant on the maximum water depth, which was only available on the fairway for the entire length of the passage from Brunsbüttel to Hamburg during high tide. All efforts made on board to remedy the technical issues failed. The engine failed for the final time at about **0414** and could not be started again afterwards. Following that, the pilot notified the VTS at about **0420**, taking the precaution of requesting tug assistance in the process. A total of seven tugs from Brunsbüttel, Stade and Hamburg were deployed. The forecabin of the distressed vessel was manned and the starboard anchor made ready to drop. The ship was being sailed at about 12 kts when the engine failed. She inevitably lost speed gradually afterwards but was still easy to steer for some time, even without propulsion. The CAPE LEONIDAS's speed had slowed down to some 4 kts by about **0501**. Since the steering had deteriorated substantially, an emergency anchor manoeuvre was unavoidable. Accordingly, the starboard anchor was first lowered and then its entire length (13 shots) deployed at **0507** (see **Figure 3**).

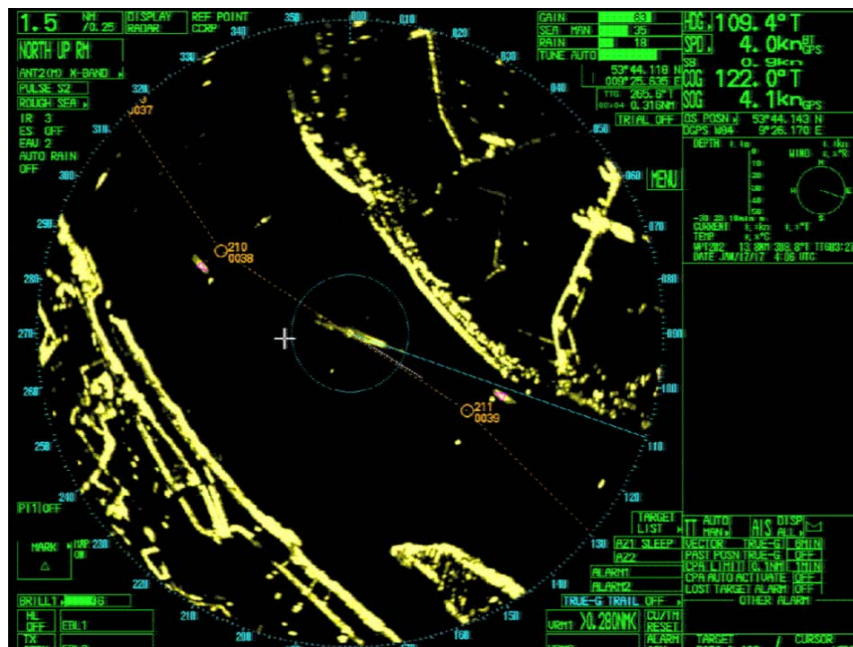


Figure 3: MV CAPE LEONIDAS – radar image at the time of the first emergency anchor manoeuvre³

² All times shown in this report are local (CET/UTC + 1 hour).

³ Source: Screenshot from the radar recording on the CAPE LEONIDAS's voyage data recorder (VDR).

This made it possible to stop the ship completely within about the following 15 minutes and hold her in a constant position from about **0523** onwards. In the meantime, the rising tide had caused the laid up vessel to sway about 180 degrees toward the sea port stem first (see Figure 4).

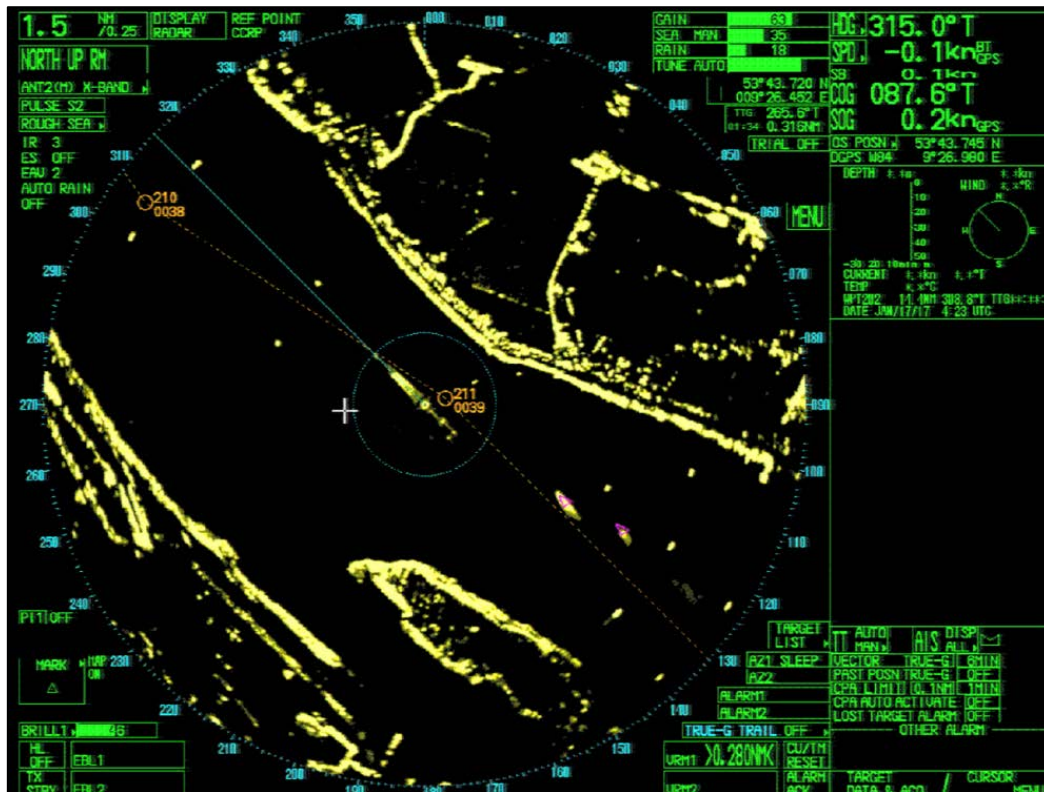


Figure 4: MV CAPE LEONIDAS at her first emergency anchorage (after swaying toward the sea)

One tug from Stade (BUGSIER 18) and then three from Brunsbüttel (WOLF, WAL and BUGSIER 15) gradually reached the CAPE LEONIDAS between **0534** and **0600**. During the above period the VTS took the decision to shift the ship about 7-8 cables down the fairway in a southerly direction to the area of fairway buoy 89 after consulting with the pilot and the ship's command of the distressed vessel. An analysis of up-to-date bearing data revealed this was the only place where a sufficiently safe water depth would be available at low tide, too, to wait without grounding for the next high tide, which was necessary for continuing the voyage.

To execute this plan, they initially started to turn the distressed vessel 180 degrees in the fairway (i.e. in the direction of Hamburg) port stem first with tug assistance at about **0606**. Two tugs (BUGSIER 18 and WOLF) had already made fast aft for this purpose. The two other tugs were positioned fore and aft on the port side of the CAPE LEONIDAS to push and stabilise. During the turning manoeuvre, which was completed by about **0651** (see Figure 5), the distressed vessel hauled in several shots of her starboard anchor's chain cable, as planned.

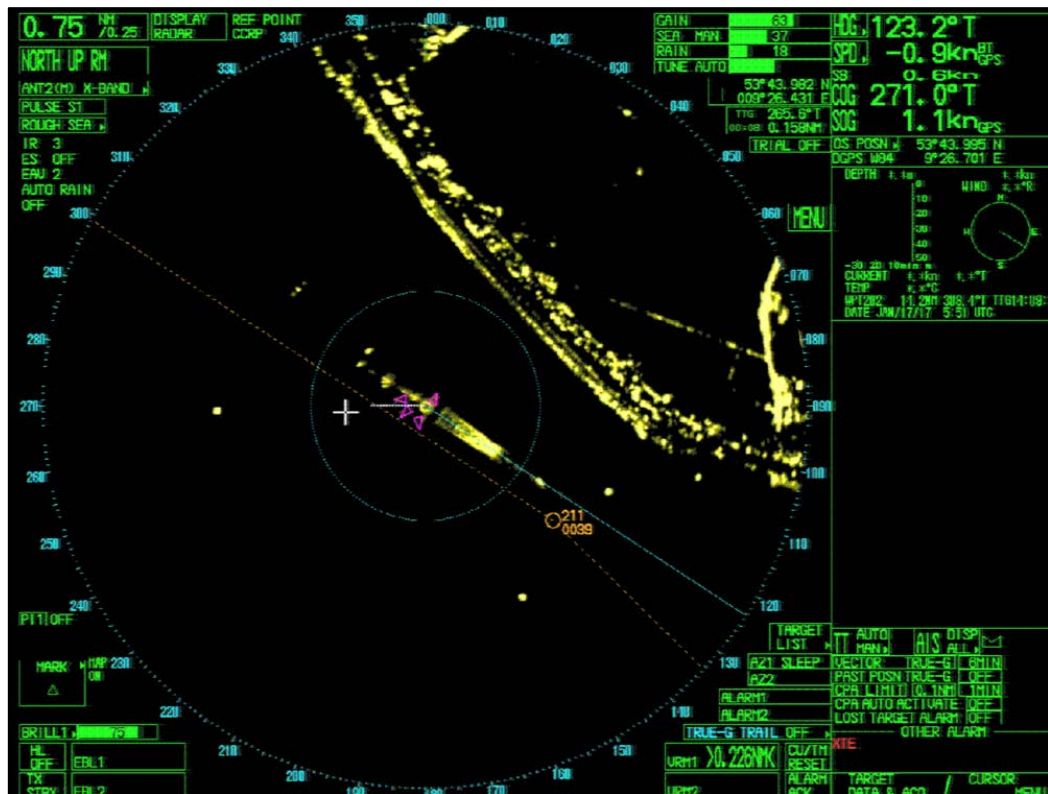


Figure 5: MV CAPE LEONIDAS after the turn required for shifting to her second anchorage

The three tugs requested from Hamburg (BUGSIER 7, BUGSIER 22 and BUGSIER 2, arrived at the distressed vessel between about **0700** and **0750**. BUGSIER 7 and BUGSIER 22 made fast at the CAPE LEONIDAS's bow. BUGSIER 2 relieved BUGSIER 15, which was stood down from the operation in order to be available in Brunsbüttel again. Through their concerted effort and in coordination with the CAPE LEONIDAS's pilot, the tugs deployed to the operating site (now six in total) ensured that the ship was in line with the River Elbe. At the same time, the distressed vessel was prepared for the forthcoming towing manoeuvre by slowly hauling in the anchor. At about **0856**, it was noticed while the last links of the anchor were being hauled in that the grapnel⁴ had been torn off the chain.

At the same time as the activities discussed above, the VTS asked the NEUWERK (multipurpose vessel belonging to the Federal Waterways and Shipping Administration) to temporarily pull in buoy 89, which was positioned where the distressed vessel was to wait on the next fairway. The NEUWERK arrived at the operating site at about **0840** and had completed her task by about **0900**.

They then carefully started to tow the CAPE LEONIDAS to the planned waiting position immediately afterwards. The NEUWERK remained there for the time being so as to assist with the orientation of the tow.

⁴ Grapnel: Anchor in its stricter meaning, i.e. device that grips the seabed, thus fixing the chain to the ground.

At **1017**, the tugs had towed the CAPE LEONIDAS to her final waiting position in the area of buoy 89, which had been pulled in. The distressed vessel then dropped her port anchor there and in the hours that followed was kept in line with the fairway with the continued support of the tugs. She was thus prevented from grounding or running aground.

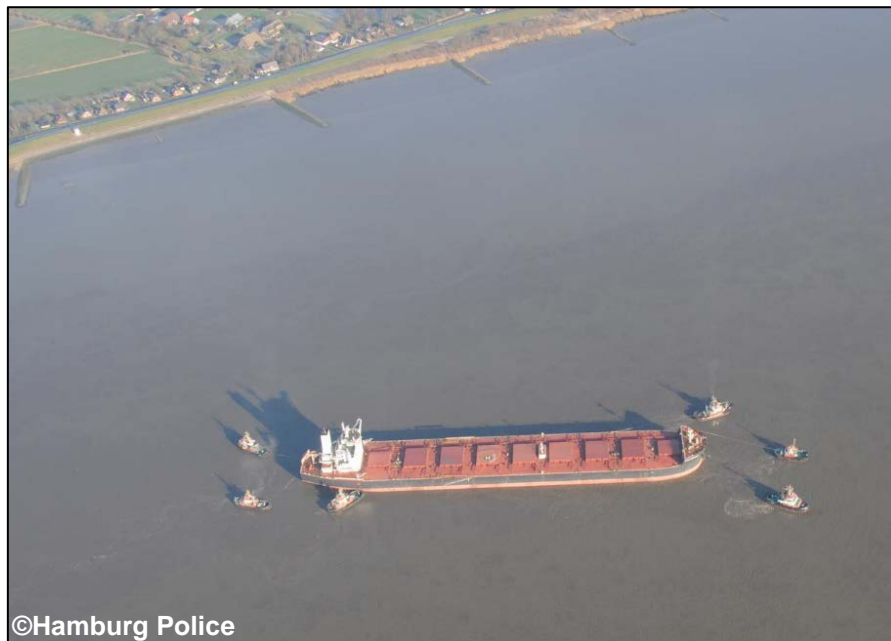


Figure 6: The MV CAPE LEONIDAS secured by tugs in her waiting position in the fairway on the River Elbe in the area of buoy 89, which had been pulled in

The towed convoy started to move toward Hamburg at about **1450** with the onset of the next tide. Due to the repair of the main engine, which had been carried out in the meantime, the distressed vessel was able to propel herself. CAPE LEONIDAS made fast at the transshipment point in the port of Hamburg at **2000**.

2.2 Course, sources and material details of the investigation

The BSU was notified about the incident shortly after the CAPE LEONIDAS's emergency anchor manoeuvre. A team of investigators boarded the ship in the port of Hamburg on **18 January 2017**. Interviews were conducted, various documents were sighted, photographs were taken and a copy of the recordings on the VDR (a FURUNO VR-3000) was made. A backup of the recorded data had been made at **1154** on the day of the incident. Accordingly, in addition to the other sources, a 13-hour data recording (from 2254 on 16 January 2017 to 1154 on 17 January 2017) could be referred to during the reconstruction and evaluation of the incident.⁵

⁵ Note: The relevant performance standards for the VDR installed specify that at least 12 hours prior to the automatic or manual initiation of a data backup must be saved.

When the incident was reported, the BSU was informed the ship had experienced technical problems with her main engine and it was with that in mind that the investigating team took the precaution of asking the director of the Marine Engineering Working Group of the Hamburg-Harburg University of Technology, Professor Dr.-Ing. Friedrich Wirz, for assistance in clarifying the technical causes of the engine failure in the capacity of expert. To this end, Professor Wirz attended the survey on board and asked the engineers for a detailed account of their observations and activities in relation to the technical problems. The expert also sighted the written and electronic recordings relating to this and overall operation of the machinery since leaving the port of loading at Narvik. To allow for a detailed analysis of this information during the course of the investigation, the investigating team took photographs and copies of the same.

The interviews on board and an initial cursory inspection of the technical recordings and alarm messages revealed that problems relating to cylinder 5's fuel supply were responsible for the engine failure. Accordingly, the technical personnel on the CAPE LEONIDAS had already changed two injectors and the puncture valve⁶ on cylinder station 5 at the emergency anchorage and was thus able to make the engine ready for use again.

During their time on board, the team of investigators and the expert acting on behalf of the BSU observed a pressure test carried out on the exchanged injectors using a test device available on the ship, which revealed that one of the two nozzles was defective. Consequently, the BSU decided to have the defective nozzle examined by a test laboratory, so as to establish the exact type and cause of the malfunction.

The team of investigators requested a sample of each type of fuel from the day tanks because the first inspection of the engine alarms carried out on board had already indicated that there had been problems with the main engine's fuel supply system when the fuel was changed from IFO⁷ to MGO⁸ in accordance with environmental legislation shortly after sailing out of the port of Narvik. The BSU arranged a laboratory examination here, too, so as to identify any problems arising from the changeover process or use of the above fuels.

⁶ Puncture valve: Component inside the injection pump.

⁷ IFO: Intermediate fuel oil (sulphurous heavy fuel oil).

⁸ MGO: Marine gas oil (fuel with low sulphur content).

2.3 Findings of the investigation

2.3.1 Preliminary notes

In addition to the chronological reconstruction of the course of the incident and ensuing crisis management, which the BSU was essentially able to perform using the analysed VDR recordings (audio and radar, in particular) and on the basis of the witness testimony outlined above in Section 2.1, the investigative work of the technical expert commissioned by the BSU formed the main focus of the investigation. The expert sighted and analysed available data and recordings concerning the technical problems on board the distressed vessel. The results of the laboratory tests on the defective injector and fuels used were also taken into account in the report he prepared for the BSU. The following Section 2.3.2 provides extracts of the material content of the report, which the BSU has abridged, edited and supplemented by various photographs for this purpose. The text has been set in italics to make it clear from its appearance that the author of the remarks in question is the expert commissioned by the BSU, Professor Dr.-Ing. Friedrich Wirz.

2.3.2 Expert opinion on the technical causes of the engine failure

2.3.2.1 Survey on board on 18 January 2017

2.3.2.1.1 Engine room log

*The last port of departure before the incident was Narvik in Norway. Narvik is located on the north-west coast of Norway and thus outside the Sulfur Emission Control Area (SECA), meaning it was possible to start the voyage with sulphurous heavy fuel oil (intermediate fuel oil – IFO). Before entering the SECA (North Sea), the fuel must be changed to one that has a maximum sulphur content of 0.1%, usually marine gas oil (MGO), however. The engine room log contained a signed and stamped document in which the changeover procedure was described chronologically, as required for any subsequent SECA compliance checks (see **Figure 7** below). This indicated that the changeover procedure from IFO to MGO (referred to there as HSFO (high sulfur fuel oil) and LSMGO (low sulfur marine gas oil), respectively) started at 0130 and was completed at 0200 on 14 January 2017, meaning it took 30 minutes. The SECA border was crossed at 0215.*

MV CAPE LEONIDAS

IN COMPLIANCE WITH SECA ZONE REGULATION, USING FUEL OIL CONTAINING 0.1 % SULPHUR OR LESS PRIOR VESSEL ENTERING SECA AREA. THE FOLLOWING PROCEDURES CARRIED OUT.

14 JAN. 2017 / 0130H LT. POSITION: LAT: 62 Deg. 06 min. N LONG: 004 Deg. - 16 min. E
PRIOR vessel entering seca area , COMMENCED change over fuel use from HSFO to LSMGO 0.1 % sulfur content:

ROB :
MDO Storage tank (P) (Designated LSMGO Storage Tank) = 90.11 MT
MGO STOR. TK. (P) = 20.32
MDO Serv. Tank (P) (LSMGO) = 43.9 MT
TOTAL: LSMGO = 154.33 MT
ROB : HSFO = 1795.08 MT

COMPLETED change over from HSFO to LSMGO 14 JAN. 2017 @ 0200H LT.
LAT: 62 deg. 02 min. N / LONG: 004 deg. 09 min. E
ROB :
HSFO = 1795.08 MT
LSMGO = 153.59 MT
(TOTAL CONSUMED LSMGO= 0.74 MT)

=ENTRY SECA ZONE=
14 JAN. 2017/ 0215H LT: LAT: 62 deg. 00 min. N / LONG: 004 Deg. 05 min. E
-Vessel ENTERING SECA AREA, remaining HSFO completely flushed out, change over fuel oil use LSMGO 0.1 % sulfur. In compliance with SECA AREA REGULATION.

ROB LSMGO TOTAL = 153.21 MT
(TOTAL CONSUMED LSMGO= 1.12 MT)
ROB :HSFO TOTAL = 1795.08 MT

Attached Bunker Delivery Note for LSMGO 0.1 % sulphur.

PREPARED BY:




Figure 7: Documentary evidence of the fuel changeover (entry into the SECA on 14 January 2017)

The engine room log contains the following handwritten entries regarding 17/01 (date of the incident):

- "0330 – Main engine initial malfunction lat. 53-52.8N long. 009-11.5E"
- "0507 – Dropped STBD anchor in pos. lat. 53-49.30N long. 009-26.80E"
- "0534 – First tugboat arrived 0726 – last tugboat arrived"
- "0854 – All chains on deck, STBD anchor missing lat. 53-44.06N long. 009-26.24E"
- "0900 – Commence shifting to emergency anchorage"
- "1018 – Dropped port anchor in pos. lat. 53-43.44N long. 009-27.27E"

- *** Replaced w/ new seal to M.E. F.O. supply pump no.1"*
- *** Replaced F.O. injectors F&A to cyl. No. 5 of M.E."*
- *** Replaced w/ recon. Spare puncture valve to cyl. No. 5 F.O inj. pump"*

2.3.2.1.2 Fuel changeover notice

Measures must be taken on board all ships to ensure a proper changeover between high- and low-sulphur fuel types since the fuel sulphur limits for the SECAs entered into force in early 2016.

Two procedures have become established:

The first is recommended by engine manufacturers and involves installing a module that performs the changeover automatically. This is where the temperature gradient (about 2 K per minute) is maintained as a reference variable, whereby the changeover period does not fall below about one hour due to the temperature differences between IFO (about 130-140 °C at injection viscosity) and MGO (roughly the ambient temperature). The actuating variable is the changeover valve (three-way valve), which fills the supply to the fuel system's mixing pipe from the IFO or MGO tank.

The second is the preferred solution of many owners for reasons of cost, where the changeover procedure is described in detail in an operating instruction to the crew, which is displayed in a notice. In particular, this points to the (minimum) changeover period. A crew member operating the changeover valve(s) executes the actual changeover manually in accordance with the instructions.

*The latter of the two procedures was found on the CAPE LEONIDAS in the form of a laminated multi-page printout (see **Figure 8** below) attached to the wall of the engine control room (ECR). It contains the following advice in several places (and regardless of the direction of the changeover): "Time required for changing over about 45-60 minutes."*

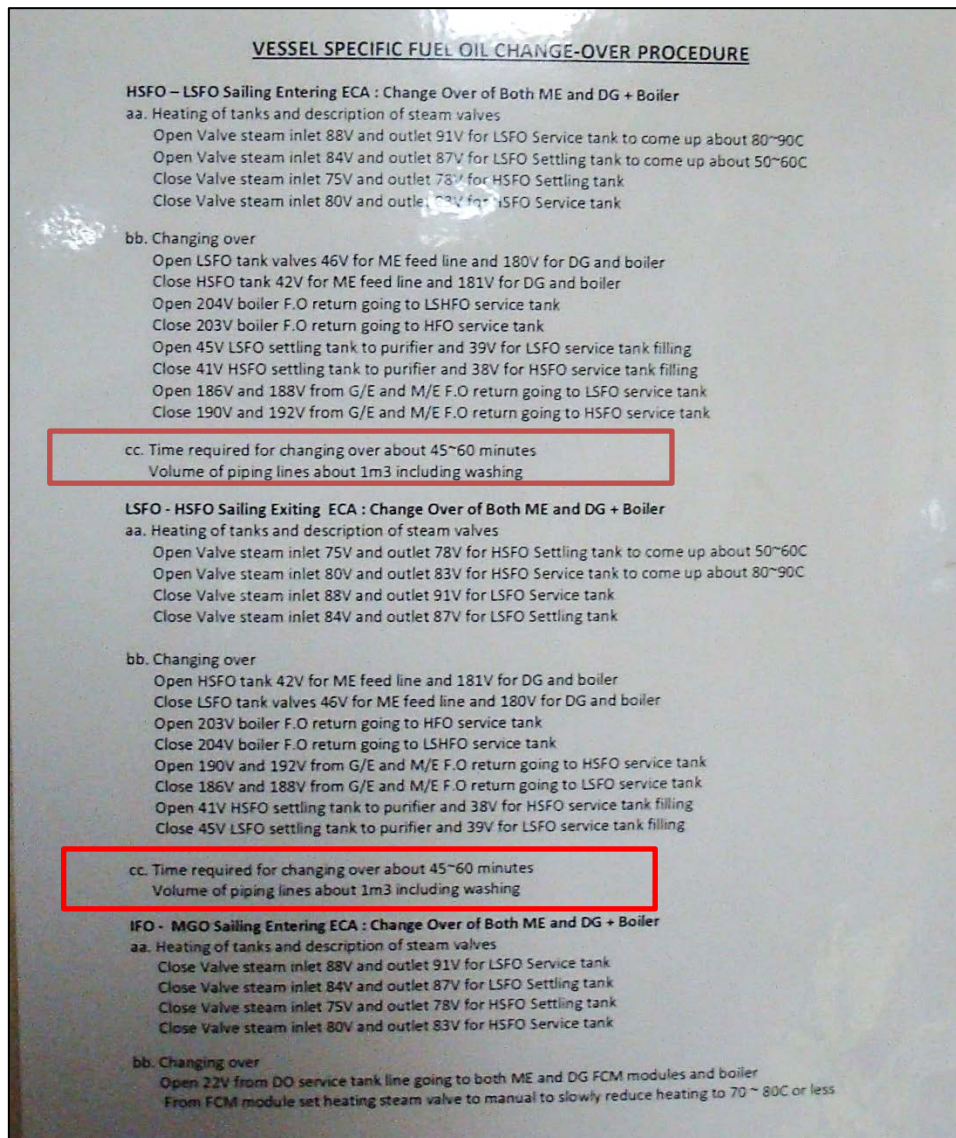


Figure 8: Fuel changeover notice in the CAPE LEONIDAS's ECR (extract)⁹

2.3.2.1.3 Puncture valve

The puncture valve, which was removed and replaced by a spare part, was available for inspection. There was no evidence to suggest a malfunction.

2.3.2.1.4 Injectors

An appliance in the engine room's workshop for storing injectors contained three of them during the survey on board. The chief engineer indicated which two had been removed from cylinder 5; the third of the three nozzles was a spare. At the request of those present, the two removed nozzles were successively clamped and pressure-tested by crew members on a test rig located next to the appliance.

⁹ Note: The red marking was inserted by the investigation report's author and shows the required period.

The pressure at which the nozzles should open/inject according to specifications (label on the test rig and the expert's experience) stands at 200-280 bar. The first of the two nozzles injected at a test pressure of about 270 bar in accordance with the specifications. On the other hand, the second nozzle did not inject after being subjected to increasing pressure up to 388 bar (see **Figure 9** below)! A further increase in the test pressure was dispensed with in the interest of the safety of those present and the test was aborted. The removed injectors were secured as evidence and examined in a laboratory subsequently.



Figure 9: Rig for pressure testing injectors in the CAPE LEONIDAS's ECR

2.3.2.1.5 Fuel samples

*IFO and MGO samples were taken from the day tanks at the request of the expert. The chief engineer provided clean sample bottles (capacity of about one litre), which he filled with the corresponding fuels from the day tanks and then labelled (see **Figure 10** below). The samples were given to the expert for later analysis.*



Figure 10: Fuel samples from the CAPE LEONIDAS's day tanks

*The expert also tried to scrape a sample of a solid black substance out of the faulty injector, which was at the top of the fuel inlet (see **Figure 11** below). The sample acquired was insufficient for later analysis, however.*



Figure 11: Secured residues from the fuel inlet of the defective injector

2.3.2.1.6 Alarms

Individual photographs starting with the time stamp 233355 on 13/01 and ending with the time stamp 122824 on 17/01 were taken of the screen of the alarm monitoring system (AMS).

2.3.2.1.7 Documents and correspondence

According to an email on the chronological order of events before and during the incident, which was sighted on board, the ship anchored off the Elbe estuary on the evening of 16/01 in the waiting roadstead, where the engine was tested and they waited for high tide. At 2124, the anchor was hauled in and the entry into the River Elbe started. A pilot transfer took place between 0316 and 0320 on the morning of 17/01. Ten minutes after the pilot transfer at 0330, the pilot reportedly asked for an increase in the rated speed so as to get to Hamburg in time on the high tide. ("Elbe River Pilot request to Master to increase RPM to catch the High Tide due next pilot (docking) at 0630hrs to berth at around 0730hrs.") The main engine started to fail at 0330 ("0330hrs – 0420hrs/17 Jan'17: M/E started to fail to increase RPM to full until the Pilot ask me what is the problem and Master told him that I have a M/E trouble and cannot start. [...]")

2.3.2.2 Subsequent examinations

2.3.2.2.1 Fuel samples

According to the expert's experience, the IFO and MGO fuel types may exhibit incompatibilities of a chemical nature and can lead to so-called asphaltene sedimentation, for example. Asphaltenes are hydrocarbon compounds that have a solid or sludge-like consistency under ambient conditions and can cause the clogging of filters and system components with narrow cross-sections. Accordingly, fuel incompatibilities can lead to injectors becoming clogged, for example. This suspicion was reinforced by the discovery of solid/wax-like black deposits in the inlet of the replaced injectors, which could no longer be isolated after the pressure test, however.

Messrs Saybolt van Duyn GmbH in Hamburg was chosen as a suitable laboratory for fuel analyses. The expert sent the two samples (IFO and MGO) to the laboratory with the aim of first analysing the two samples in relation to their specifications and then carrying out a compatibility test. In the case of the latter, both substances are mixed and stored for a certain period of time at an elevated temperature. Following that, a check is made to establish whether the mixture is homogeneous or there are sedimentations.

The laboratory's analysis report dated 6 February 2017 indicated that none of the test results were conspicuous. This means that incompatibility of the fuels involved in the changeover can, with high probability, be ruled out as being partly or solely responsible for the incident. The cause of the solid deposits in the injectors (even though the IFO was fluid at ambient temperature) could not be clarified conclusively.

2.3.2.2.2 Injection system/injectors

The CAPE LEONIDAS's main engine has a conventional mechanically controlled injection system and a plunger injection pump and two injectors for each cylinder.

According to the expert's findings, an increasing number of problems have occurred with components of the injection system since the SECAs were introduced and the resulting fuel changeovers required when entering or leaving them. The problems have two main causes:

(1) The different viscosities of IFO and MGO

One cause is related to the different viscosities of IFO and MGO at the same temperature. While the viscosity of IFO is extremely high at ambient temperature, sometimes even falling below the pour point (i.e. is solid), MGO is relatively thin at ambient temperature. One property both liquids have is that their viscosity decreases as the temperature increases (the substance becomes thin when heated and viscous when cooled), but at different levels.

This can lead to effects that may be compared with a heart attack or exactly the opposite (fall in blood pressure). If viscosity is too high, the viscous fuel cannot be atomised sufficiently during the injection process and combustion tends to produce soot, for example. In the worst case, when the fuel cools below the pour point, the excessive viscosity can lead to the formation of plugs which block the injector's passages. That would be equivalent to a heart attack.

On the other hand, fuel in the injection pump (comparable to a medical syringe consisting of plunger and cylinder) can leak out through the gaps to an undesirable extent when viscosity is too low. As a result, the required injection pressure cannot develop and the leakage in the injection pump increases.

Another extremely critical aspect of insufficient viscosity is that the viscosity is equivalent to the fuel's lubricity, which is essential for the lubrication of the moving parts in the injection system, i.e. the pump plunger in the pump cylinder and the needle in the injectors. If lubricity is too low, the friction caused by parts sliding against each other tends to increase within an extremely short period, resulting in friction wear and an ensuing seizure.

The fact that these two effects (resulting from excessive and insufficient viscosity of the mixing fuels) can occur simultaneously when the fuels are spontaneously mixed has an unfavourable impact. The initial situation is such that IFO is already preheated to about 70 °C in the day tank and finally to about 140 °C in the fuel system to adjust the injection viscosity, whereas MGO does not need to be preheated and can become dangerously thin even at temperatures above ambient temperature.

For example, if the engine was previously operated with IFO outside the SECA, then the entire fuel system (including injection components) is warm. This is because the injection system requires a certain viscosity, which corresponds to the above temperature of up to 140 °C for IFO and is adjusted by preheating. Of course, the insulated lines and components of the system are then also heated to about this temperature.

When cold MGO then flows into the system during the changeover process, two things happen. First the MGO is heated rapidly in the warm environment, causing its viscosity to drop even further. At the same time, the remaining IFO is cooled rapidly, causing its viscosity to increase and in extreme cases even 'freeze' locally.

Liquids with differing densities and temperatures, as in the present case, do not mix with each other but remain isolated in adiabatic bubbles. This effect is seen in lava lamps, for example, where water and wax never mix. Accordingly, the two undesired effects discussed occur cumulatively. The low-viscosity MGO bubbles lead to a failure of the lubrication of the components and at the same time solid IFO plugs can become detached and block the injection bores. A seizure and 'heart attack' are the outcome. The same can happen in the opposite case, i.e. when the change from MGO to IFO mode is made too quickly upon leaving the SECA.

(2) Thermal expansion of components

The other cause of possible technical problems with components of the injection system is related to the differing temperatures at the same viscosity, i.e. the opposite of that described above. However, the problem here is not the liquids but rather the components (or their thermal expansion). Almost every material tends to expand when heated and contract when cooled. This also applies to iron and steel materials.

Indeed, all the component parts (pump and nozzle) of the injection system consist of steel and therefore have similar coefficients of thermal expansion (parameter that defines the change in volume as a function of the temperature change). This means that the volume of all components matches at a uniform temperature and the required clearances are thus maintained. Accordingly, everything fits together at both high and low temperatures with the limitation that the geometry of the parts has a certain impact on expansion or contraction.

The situation is different with rapid temperature changes. For example, if cooling is rapid (which is the case when switching from IFO to MGO mode when entering a SECA), it is the surfaces of the components that cool down to begin with. In the case of plunger and cylinder or needle and nozzle body combinations, this means that the bored body (i.e. cylinder or nozzle body) contracts rapidly, while the body made of solid material (i.e. plunger or needle) begins to contract at the surface but the core, still warm, opposes this contraction. The outcome here is that the internal dimension of the bore contracts faster than the external dimension of the solid body. This reduces the clearance between the two – down to as much as zero in extreme cases.

As a result, the (movable) solid body is trapped in the bored outer body. The friction rises sharply in the meantime due to insufficient play and causes the surfaces to heat up, at which the viscosity drops and the lubricity of the fuel finally fails. At the same time, the

liquid is forced through the gap, which is actually critical for dissipating the heat generated at precisely this moment. A kind of chain reaction takes place within a very short time, which inevitably leads to the seizure and/or jamming of the components rubbing against each other. Of course, under certain structural circumstances a similar effect can occur when the changeover is in the opposite direction (i.e. from MGO to IFO mode upon leaving a SECA).

The two causes discussed under (1) and (2) usually occur together, mutually reinforcing the other's effect because the liquids and components interact.

The expert suspects that in this particular case either clogging or jamming of the affected injector may have caused the engine failure.

For this reason an analysis of the secured nozzle was carried out at MAN PrimeServ's materials testing laboratory in Hamburg. The company (service branch of the engine manufacturer) is on the one hand familiar with the injectors and on the other hand it operates an independent testing laboratory with recognised expertise in metallurgy and tribology.

On 27 January 2017, the BSU's team of investigators and the expert took the affected injector to MAN PrimeServ in Hamburg and observed the initial assessment.

This revealed that the nozzle needle was stuck in the nozzle body and could only be forced out with the aid of a mechanical press after the nozzle body had been unscrewed from the upper part of the nozzle.

That initially explained why the nozzle failed to open/inject within the specified pressure range on the ship's test rig (pressing tool). The nozzle needle exhibited signs of surface damage but it was not possible to see inside the nozzle body to begin with.

It was agreed at the premises that the nozzle body would be sawed in a subsequent examination and that the surfaces of both the nozzle body and needle would be examined microscopically using a scanning electron microscope. The main question was whether the surface damage was caused by thermal effects or the presence of abrasive foreign particles. The latter would be a simple explanation of the jamming, which would have pointed to inadequate care, quality or preparation of the fuel.

*The results of the analysis were provided in the MAN laboratory report dated 15 February 2017 (**see Annex to investigation report**). It is noted in the summary that no signs of corrosion or foreign particles could be found. However, chips on the surface of the outer casing would be an indication that both components had jammed together. Consequently, it is reportedly reasonable to assume that a thermal effect caused the two components to jam.*

2.3.2.2.3 Analysis of the alarms

The expert analysed the alarm messages secured in the ECR during the survey on board, which are continuously stored in the computerised AMS. Since an initial cursory examination of the alarm recordings, which was made on board, indicated a connection between the technical faults and the fuel changeover on entering the SECA, the expert focused his analysis on the period starting when the changeover process (from about 0130 on 14/01) took place until the morning of 17/01.

The expert believes that the following conclusions can be drawn from the alarms listed:

- All components of the main engine's and auxiliary engine's fuel supply systems exhibited abnormal operating conditions with respect to pressures and temperatures over the entire period under consideration.
- Since 0302 on 14/01 (i.e. less than one hour after the fuel changeover time recorded in the engine room log), the main engine exhibits a deviation in cylinder 5's exhaust gas temperature (see row outlined in white below in **Figure 12**). This deviation is repeated. The injection nozzle subsequently identified as defective also comes from cylinder station 5.

The probable explanation for this is that due to the aforementioned effects, one of cylinder 5's two injectors jammed shortly after the changeover process, namely in a closed state (as revealed by the pressure test). This means that fuel could only be injected into cylinder 5 through the remaining, intact injection nozzle. The remainder of the mass of the fuel fed by the injection pump probably discharged via leakage under increased (injection) pressure due to the half throttle cross-section. Consequently, significantly less fuel was injected into cylinder 5 than into the other cylinders per working cycle. As a result, this cylinder was subjected to less load than the other cylinders, causing its exhaust gas temperature to drop by more than 60 K as compared to the other cylinders. The associated alarm is normal because the exhaust gas temperatures of individual cylinders is compared with the mean value of all cylinders and must not deviate from the mean value by more than 60 K.



DESC	FUNC	VALUE	UNIT	EVENT	LIMIT	DATE	TIME
AUX. BOILER LOW OIL TEMP	TAL	OFF		ALARM	OFF	13/01/2017	23:33:55.80
AUX. BOILER LOW OIL TEMP	TAL	OFF		ALARM	OFF	13/01/2017	23:33:56.80
AUX. BOILER LOW OIL TEMP	TAL	OFF		DI ACK	OFF	13/01/2017	23:33:59.00
AUX. BOILER COMMON SHUTDOWN	SHD	OFF		DI ACK	OFF	13/01/2017	23:33:59.00
AUX. BOILER LOW OIL TEMP	TAL	ON		Normal	OFF	13/01/2017	23:33:59.00
AUX. BOILER LOW OIL TEMP	TAL	ON		DI ACK	OFF	13/01/2017	23:34:03.00
AUX. BOILER LOW OIL TEMP	TAL	ON		Normal	OFF	13/01/2017	23:34:03.00
AUX. BOILER LOW OIL TEMP	TAL	ON		Normal	OFF	13/01/2017	23:34:11.00
AUX. BOILER COMMON SHUTDOWN	SHD	ON		Normal	OFF	13/01/2017	23:34:11.00
AUX. BOILER LOW OIL TEMP	TAL	ON		DI ACK	OFF	13/01/2017	23:34:12.00
AUX. BOILER LOW OIL TEMP	TAL	ON		Normal	OFF	13/01/2017	23:34:12.00
AUX. BOILER LOW OIL TEMP	TAL	OFF		DI ACK	OFF	13/01/2017	23:34:14.85
AUX. BOILER LOW OIL TEMP	TAL	ON		Normal	OFF	13/01/2017	23:34:15.00
AUX. BOILER LOW OIL TEMP	TAL	OFF		DI ACK	OFF	13/01/2017	23:34:19.87
AUX. BOILER LOW OIL TEMP	TAL	ON		Normal	OFF	13/01/2017	23:34:19.87
AUX. BOILER LOW OIL TEMP	TAL	OFF		DI ACK	OFF	13/01/2017	23:34:22.78
AUX. BOILER LOW OIL TEMP	TAL	ON		Normal	OFF	13/01/2017	23:34:22.78
AUX. BOILER LOW OIL TEMP	TAL	ON		DI ACK	OFF	13/01/2017	23:34:24.09
AUX. BOILER LOW OIL TEMP	TAL	ON		Normal	OFF	13/01/2017	23:34:24.09
AUX. BOILER LOW OIL TEMP	TAL	ON		DI ACK	OFF	13/01/2017	23:35:33.32
NO 3 G/E JET FAIL	XA	ON		Normal	OFF	13/01/2017	23:35:33.32
NO 3 G/E JET FAIL	XA	OFF		ALARM	OFF	14/01/2017	00:39:37.40
NO 3 G/E JET FAIL	XA	ON		DI ACK	OFF	14/01/2017	00:40:10.45
COMMON ALARM FOR M/E FSU	XA	ON		Normal	OFF	14/01/2017	00:40:10.45
COMMON ALARM FOR M/E FSU	XA	OFF		ALARM	OFF	14/01/2017	00:40:10.45
COMMON ALARM FOR M/E FSU	XA	ON		Normal	OFF	14/01/2017	01:51:58.00
AUTO FILTER CLOGGED FOR M/E FSU	XA	OFF		DI ACK	OFF	14/01/2017	01:52:25.54
COMMON ALARM FOR M/E FSU	XA	OFF		ALARM	OFF	14/01/2017	01:53:21.85
COMMON ALARM FOR M/E FSU	XA	OFF		ALARM	OFF	14/01/2017	01:58:17.80
AUTO FILTER CLOGGED FOR M/E FSU	XA	ON		Normal	OFF	14/01/2017	01:58:18.00
COMMON ALARM FOR G/E FSU	XA	OFF		DI ACK	OFF	14/01/2017	01:58:45.00
COMMON ALARM FOR G/E FSU	XA	OFF		DI ACK	OFF	14/01/2017	01:58:57.10
ME NO 5 CYL EXH GAS OUT TEMP DEV.	XA	ON		ALARM	OFF	14/01/2017	01:58:57.10
COMMON ALARM FOR G/E FSU	XA	OFF		Normal	OFF	14/01/2017	02:37:33.80
ME NO 5 CYL EXH GAS OUT TEMP DEV.	TIAH	-81.26	Deg.C	ALARM	OFF	14/01/2017	02:38:01.10
COMMON ALARM FOR G/E FSU	XA	ON		DI ACK	OFF	14/01/2017	03:02:50.80
ME NO 5 CYL EXH GAS OUT TEMP DEV.	TIAH	-84.89	Deg.C	ALARM	-80.00	14/01/2017	03:03:40.80
COMMON ALARM FOR G/E FSU	XA	ON		LO ACK	OFF	14/01/2017	03:03:40.80
ME NO 5 CYL EXH GAS OUT TEMP DEV.	XA	ON		Normal	OFF	14/01/2017	03:03:50.43
AUTO FILTER CLOGGED FOR G/E FSU	TIAH	-59.82	Deg.C	DI ACK	OFF	14/01/2017	03:03:57.43
COMMON ALARM FOR G/E FSU	XA	OFF		L Norm	OFF	14/01/2017	03:04:40.00
COMMON ALARM FOR G/E FSU	XA	OFF		ALARM	-80.00	14/01/2017	04:15:15.40

Figure 12: Photograph of the CAPE LEONIDAS's AMS screen dated 14 January 2017

- The failure of the fuel-fired auxiliary boiler on 16/01, as demonstrated by corresponding alarm recordings, also points to viscosity and temperature problems during the fuel changeover. As a result, the bunker tanks are not preheated.
- Since 090038 on 16/01, the engine was temporarily not ready for operation and therefore evidently switched off. This must have been done manually, as no alarms indicate an automatic shutdown.
- It appears that there were repeated attempts to restart the engine on 16/01. Alarms for stopping the engine are absent at times. The failed attempts are indicated by the low starting air pressures, as well as a corresponding alarm at 210603.
- In the transition from 16/01 to 17/01, it appears that the start was successful because the temperature deviation alarm for cylinder 5 issued again at 032904 on 17/01, indicating that the engine was running but also the continuing problem of the jammed nozzle.

- A reduction in power (or rated speed) is then indicated within a few seconds and the deviation in cylinder 5's exhaust gas temperature increases by a further 15 K. In this case, the automated system has a second setpoint, which besides issuing an alarm ('yellow alarm') initially indicates a power reduction if the deviation continues to increase and later executes one ('red alarm') if the temperature deviation fails to normalise.
- One second later, at 032918, the automated system triggers auto slow down operation, i.e. the indicated power reduction (see **Figure 13**). This alarm (or reduction) coincides with the time of the start of the engine failure recorded in the engine room log. Consequently, the author believes it represents a critical moment.



DESC	FUNC	VALUE	UNIT	EVENT	LIMIT	DATE	TIME
ME START FAIL	XA	OFF		ALARM	OFF	16/01/2017	21:06:03.00
ME START FAIL	XA	OFF		DI ACK	OFF	16/01/2017	21:06:43.00
ME START FAIL	XA	OFF		Normal	OFF	16/01/2017	21:07:05.85
G/E LO PURI. ABNORMAL	XA	OFF		ALARM	OFF	16/01/2017	23:06:34.40
G/E LO PURI. ABNORMAL	XA	OFF		DI ACK	OFF	16/01/2017	23:07:17.00
G/E LO PURI. ABNORMAL	XA	ON		Normal	OFF	16/01/2017	23:08:03.00
G/E LO PURI. ABNORMAL	XA	OFF		ALARM	OFF	16/01/2017	23:26:13.60
G/E LO PURI. ABNORMAL	XA	OFF		DI ACK	OFF	16/01/2017	23:26:52.09
G/E LO PURI. ABNORMAL	XA	ON		Normal	OFF	16/01/2017	23:27:48.06
G/E LO PURI. ABNORMAL	XA	OFF		ALARM	OFF	16/01/2017	23:29:50.00
G/E LO PURI. ABNORMAL	XA	ON		Normal	OFF	16/01/2017	23:30:28.56
G/E LO PURI. ABNORMAL	XA	OFF		ALARM	OFF	16/01/2017	23:30:36.03
G/E LO PURI. ABNORMAL	XA	OFF		DI ACK	OFF	16/01/2017	23:32:51.00
G/E LO PURI. ABNORMAL	XA	OFF		DI ACK	OFF	16/01/2017	23:33:29.21
G/E LO PURI. ABNORMAL	XA	ON		Normal	OFF	16/01/2017	23:33:32.21
ALCU COMMON ALARM	XA	OFF		ALARM	OFF	17/01/2017	03:27:28.20
ALCU COMMON ALARM	XA	OFF		DI ACK	OFF	17/01/2017	03:28:08.32
ALCU COMMON ALARM	XA	ON		Normal	OFF	17/01/2017	03:28:40.06
ME NO.5 CYL EXH GAS OUT TEMP DEV.	TIAH	-84.95	Deg.C	< L	-80.00	17/01/2017	03:28:04.80
ME EMCY SLOW DOWN PREWARNING	XA	OFF		ALARM	OFF	17/01/2017	03:29:12.20
ME NO.5 CYL EXH GAS OUT TEMP DEV.	TIAH	-75.48	Deg.C	< LL	-70.00	17/01/2017	03:29:17.60
ME AUTO SLOW DOWN	SLA	OFF		ALARM	OFF	17/01/2017	03:29:18.40
ME NO.5 CYL EXH GAS OUT TEMP DEV.	TIAH	88.82	Deg.C	LO ACK	88.82	17/01/2017	03:29:45.76
ME EMCY SLOW DOWN PREWARNING	XA	OFF		DI ACK	OFF	17/01/2017	03:29:51.56
ME EMCY SLOW DOWN PREWARNING	XA	OFF		DI ACK	OFF	17/01/2017	03:29:53.71
ME NO.5 CYL EXH GAS OUT TEMP DEV.	TIAH	-77.71	Deg.C	Normal	OFF	17/01/2017	03:29:56.25
ME AUTO SLOW DOWN	SLA	OFF		LL ACK	-70.00	17/01/2017	03:29:56.25
ME NO.5 CYL EXH GAS OUT TEMP DEV.	SLA	OFF		DI ACK	OFF	17/01/2017	03:29:58.25
ME NO.5 CYL EXH GAS OUT TEMP DEV.	TIAH	-89.14	Deg.C	Normal	OFF	17/01/2017	03:41:52.17
ME NO.5 CYL EXH GAS OUT TEMP DEV.	TIAH	-59.94	Deg.C	LL Norm	-70.00	17/01/2017	03:41:58.00
FWD. I.C.C.P ABNORMAL	XA	OFF		L Norm	-80.00	17/01/2017	03:43:13.92
COMMON ALARM FOR M/E FSU	XA	OFF		ALARM	OFF	17/01/2017	04:00:06.00
COMMON ALARM FOR M/E FSU	XA	OFF		DI ACK	OFF	17/01/2017	04:00:51.10
VISCOCITY LOW FOR M/E FSU	XA	OFF		ALARM	OFF	17/01/2017	04:05:59.00
AUTO FILTER CLOGGED FOR M/E FSU	VAL	ON		Normal	OFF	17/01/2017	04:06:34.21
COMMON ALARM FOR M/E FSU	XA	ON		Normal	OFF	17/01/2017	04:06:55.09
COMMON ALARM FOR M/E FSU	XA	ON		Normal	OFF	17/01/2017	04:06:55.09
COMMON ALARM FOR M/E FSU	XA	OFF		DI ACK	OFF	17/01/2017	04:07:14.87
COMMON ALARM FOR M/E FSU	XA	OFF		ALARM	OFF	17/01/2017	04:08:19.00
COMMON ALARM FOR M/E FSU	XA	ON		Normal	OFF	17/01/2017	04:10:04.51
ALCU COMMON ALARM	XA	OFF		DI ACK	OFF	17/01/2017	04:10:17.20

Figure 13: Photograph of the CAPE LEONIDAS's AMS screen dated 17 January 2017

- Several attempts to start the engine are made in the hours that follow but all fail.

2.3.2.2.4 Analysis of the VDR data

The data set recorded on the VDR begins at 2254 on 16/01, i.e. the evening before the incident. Accordingly, the time of the fuel changeover in the early morning of 14/01 was not available for the analysis.

Based on the VDR recording, the main engine failed for the final time (interpreted by the drop in the rated speed to zero) at 0414 on 17/01.

Figure 14 first shows the main engine's rated speed curve (setpoint and actual), which was derived from an initial VDR data list (NMEAroh.xlsx). The BSU provided this list, which is not very granular in terms of time (interval of five minutes), to the expert.

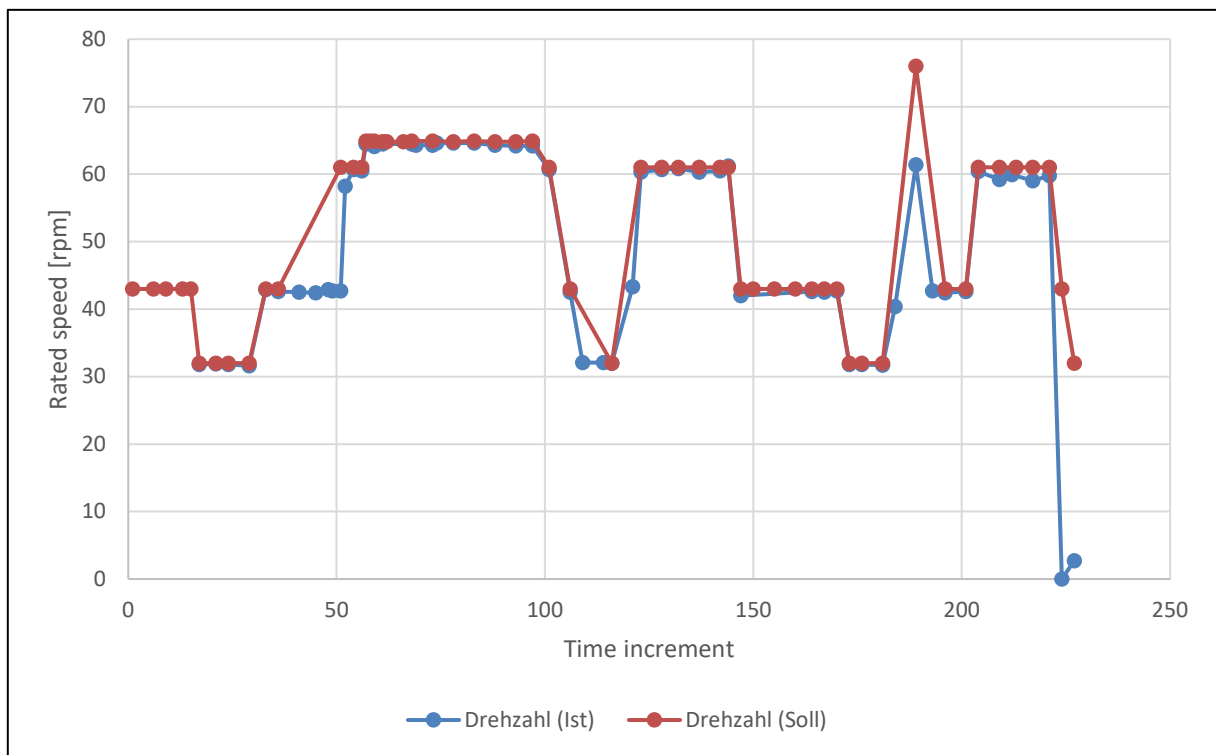


Figure 14: Rated speed curve from 2254 on 16/01 up until the incident (5-minute grid)

The display starts at 2254 on 16/01 and ends at 0419 on 17/01 (time increment 230). The penultimate time increment is 0414. At this point, the actual rated speed dropped to zero, even though the setpoint is 43 rpm. This point in time can be interpreted as the time of the failure. Various changes in rated speed are visible in the previous hour, where the rated speed setpoint is increased to some 76 rpm at about time increment 190. This is followed by an increase in actual rated speed to only 62 rpm. This increase is followed by a reduction in the rated speed, then another increase to 62 rpm and finally the shutdown of the engine at time increment 229, even though the rated speed setpoint still stands at 43 rpm.

To facilitate improved interpretation of the rated speed curve, the BSU provided the expert with the relevant VDR data in a more granular resolution (increments of one second). This can be seen in **Figures 15 and 16**.

Figure 15 shows the time range on 17/01 from 033000 (time increment 1) to 041635 (time increment 792). **Figure 16** shows a close-up of the time range from 0407 to 0416 on 17/01, i.e. the last relevant minutes leading up to the engine coming to a standstill.

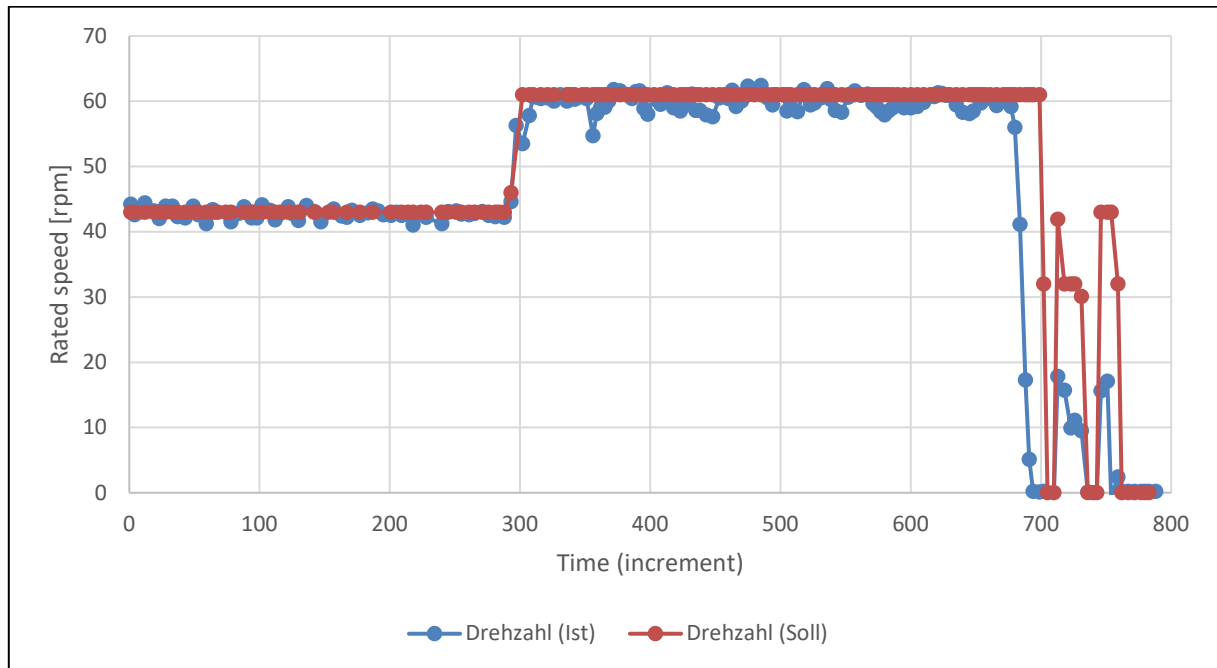


Figure 15: Rated speed curve from 0330 on 17/01 up until the incident (1-second grid)

Figure 15 shows that after a stable rated speed level of 43 rpm (setpoint = actual), the rated speed has also risen to a stable level of about 61 rpm (setpoint = actual). However, the rated speed drops to zero at time increment 680, despite the constant setpoint of 61 rpm. The setpoint reacts shortly after and is also set at zero. This is followed by several setpoints of 43 rpm, each followed by a short increase in rated speed to about 18 rpm, until both setpoint and actual stop at zero. The latter operations can be interpreted as start attempts. The automated system specifies a setpoint which leads to activation of the start-up air system. As a result, the actual rated speed increases (but not beyond the pneumatic actuation speed), at which the start-up attempt is aborted in each case.

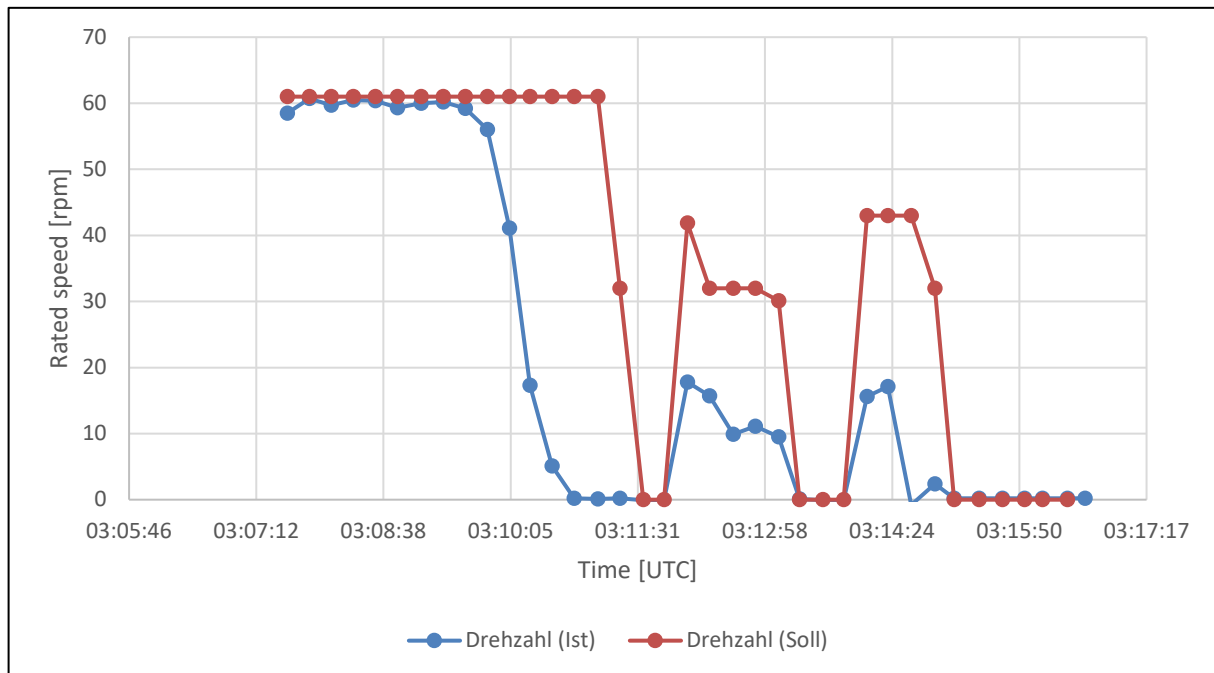


Figure 16: Rated speed curve (close-up) at the moment the incident occurred

Figure 16 shows this operation in magnified resolution. After the engine failed at 0409 (actual rated speed drops to zero, rated speed setpoint remains at 61 rpm), the automated system responds twice with rated speed setpoints of 43 rpm, which the engine cannot adhere to, however. The time at 0414 can be interpreted as meaning that the start-up attempts were abandoned either due to the automated system or manual intervention.

2.3.2.3 Interpretation of the findings and cause of failure

A comparison of the findings made during the survey on board, the analysis of the alarm list and the VDR data implies that the engine had to be stopped due to the jammed injector at cylinder 5 and the resulting (and with increased load rising) deviation of the exhaust gas temperature of cylinder 5 at 0414 on 17/01 and could not be started again, meaning the ship was no longer under command.

2.3.2.4 Reconstruction of the course of the incident

The below reconstruction of the presumed course of the incident from a technical standpoint is based on the factual indications and the expert's interpretation of them.

Accordingly, the changeover from IFO to MGO began shortly before entering the SECA at about 0130 on 14/01. The first relevant alarms for the main engine's fuel supply system were issued during this period. The changeover was carried out manually in accordance with the technical circumstances on board the ship and took a total of 30 minutes according to the relevant entry in the engine room log. The operation was therefore carried out in a shorter period of time than that specified on the notice board in the ECR.

Cylinder 5's exhaust gas temperature dropped about an hour later. It seems that one of cylinder 5's two injectors was jammed from this point in time. Although the jammed injector caused the exhaust gas temperature to deviate from the mean value of the other cylinders, it did not affect the engine's running capability to begin with.

At least in the recording range available on the VDR, the voyage was continued with the rated speed of the engine (or ship's speed) reduced. Repeated attempts to carefully increase the speed over the critical rated speed range in respect of torsional vibrations (barred speed range – >61 rpm here) were always followed by a reduction to a low rated speed below the critical speed range (<43 rpm). Accordingly, it seems that the deviation of cylinder 5's exhaust gas temperature was always within the yellow alarm range of <60 K. After the pilot transfer at 0330 on 17/01, an attempt was made to increase the rated speed at the request of the pilot so as to raise the ship's speed in order to reach Hamburg on the current high tide, however. As a result, the deviation of cylinder 5's exhaust gas temperature became so high that the engine was or had to be switched off. Subsequent start-up attempts were unsuccessful.

2.3.2.5 Summary and conclusions of the expert

In all likelihood, the subsequent engine failure was caused by a manual changeover from IFO to MGO being executed too quickly before entering the SECA two days prior to the incident.

One of cylinder 5's two injectors probably jammed because of the changeover being executed too quickly, causing this cylinder's exhaust gas temperature to fall compared to the mean value of the other cylinders. This was detected by the automated system and the alarm system. Continuing the voyage at a reduced speed (or rated speed) prevented an even greater deviation. After the Elbe pilot recommended an increase in speed (without knowing about the restricted engine operation) so as to complete the last leg of the voyage in a timely manner, the rising temperature deviation caused an engine shutdown and it could not be restarted again.

The expert believes that the wording of the fuel changeover instructions posted in the ECR, according to which the changeover should take 'about' 45-60 minutes, is open to misinterpretation. Individuals without in-depth knowledge of the technical facts may interpret the wording in question such that this information is to be understood as a maximum period. In fact, it is to be understood as a minimum period, however. With that in mind, it is recommended that the word 'about' be replaced by the phrase 'at least'.

3 CONCLUSIONS

3.1 Cause of engine failure

The laboratory tests carried out on the defective injector and the fuels used, as well as the expert acting on behalf of the BSU's detailed analysis of alarms relating to operation of the main engine recorded by the CAPE LEONIDAS's AMS indicate that it is highly likely that thermal effects about two days before the incident led to the jamming of one of the two injectors of the main engine's cylinder 5. As a result, this cylinder's exhaust gas temperature dropped permanently. This shortcoming was initially compensated for by the main engine's automated system. In the course of the increase in speed required during the voyage on the River Elbe, the negative effects of the restricted operability of cylinder 5 on overall operation of the main engine intensified to such an extent that an engine shutdown was unavoidable, however.

The aforementioned thermal effects on the injector in question were probably caused by the changeover to low-sulphur fuel (MGO) when the CAPE LEONIDAS entered the SECA being executed too quickly. The expert acting on behalf of the BSU gave a convincing explanation in his report, extracts of which are provided above, that fuel changes executed too quickly can adversely affect the fuel system – the functionality of injectors, in particular – and the reasons for this.

What is certain is that the time specified in the operating instructions for the changeover procedure ("*Time required for changing over about 45 ~ 60 minutes.*") posted in the ECR was not complied with during the changeover to MGO early in the morning of 14 January 2017 and that the injector defect most probably happened at about the same time as this changeover process.

The sequence of events and the physical effects associated with the fuel changeover processes in question, as described by the expert, indicate that the chain of cause and effect leading to the final engine failure started with the fuel changeover upon entry into the SECA being executed too quickly.

In the expert's view, which the BSU agrees with unreservedly, the ambiguous or unclear wording in the operating instructions for the changeover procedure, which states that the changeover 'requires' a period of 'about' 45-60 minutes, may have played a decisive role in the changeover being executed too quickly. Although individuals without in-depth knowledge of the physical effects arising from temporary fuel mixing may interpret the wording in question such that this information is to be understood as a maximum period, it is actually the minimum period that must be observed in order to rule out adverse consequences for the functioning of the fuel system and thus for the main engine as a whole. With that in mind, the phrase 'at least' should be used rather than the word 'about'.

Given the fundamental importance of the subject, the issue with the discrepancy between the misleading but technically very important requirement in the operating instructions and the actual (shorter) period of time in which the fuel changeover was executed two days before the incident had already been discussed with the engineers of the ship in the ECR during the survey on board and they stated that the notice would be changed.

3.2 Crisis management

Besides the temporary need for the ship to make fast at an emergency anchorage in the fairway and the ensuing partial obstruction of shipping traffic on the River Elbe, the failure of the CAPE LEONIDAS's main engine had no impact on the ship or environment. In particular, it was possible to avert the threat of the ship grounding or running aground and any ensuing environmental pollution or longer-term closure of the approach to the port of Hamburg.

The analysis of the recording on the VDR has revealed that the extremely minor impact of the incident is in the main due to the pilot's prudent and technically sound actions on board the CAPE LEONIDAS. The BSU believes his decision, taken in consultation with the VTS, to first continue steering the ship up the River Elbe with decreasing momentum after the engine failed, and his activities relating to coordination of the tug operation in particular, merit the highest recognition. This assessment applies equally to the skippers and other crew members of the tugs involved in securing the CAPE LEONIDAS for several hours.

3.3 Concluding remarks




The investigation into the engine failure on board the CAPE LEONIDAS has once more confirmed the fundamental insight that technical measures relating to the operation and/or design of ships, which contribute to enhancing environmental protection and are the result of relevant international agreements and regulations, lead to new risks in terms of safe ship operation which in turn can result in major hazards for ship crews and the environment. This means it is all the more important that the specific and any possible new risks arising from the introduction of new technologies, as well as any associated precautionary measures requiring consideration, be given the requisite attention when organising the safe operation of ships and, in particular, when educating and training seamen. Since this insight is not directed at a specific, narrowly defined group of addressees and since the CAPE LEONIDAS incident was largely without consequences, the BSU is abstaining from issuing a safety recommendation in connection with this incident. The publication of this summary investigation report aims to provide both experts and interested members of the general public with the opportunity to take note of the causes of the CAPE LEONIDAS incident, especially against the background of the affected field of tension in which the system requires that ship safety on one hand and enhanced environmental protection requirements on the other often circulate.


4 SOURCES

- Information from on board the CAPE LEONIDAS (witness testimonies, documents)
- Recordings from the CAPE LEONIDAS's VDR
- Alarm log from the CAPE LEONIDAS's machinery
- Examination Report 2017/0052 dated 15 February 2017 'Materials-related testing on a damaged fuel injection valve', MAN Diesel & Turbo SE PrimeServ Hamburg (materials testing laboratory)
- Analysis Report 10303/00014027.1/L/17 (fuel analysis) dated 6 February 2017, Saybolt van Duyn GmbH, Hamburg
- Expert opinion and analysis report on the incident involving the MV CAPE LEONIDAS on the River Elbe in January 2017 dated 5 July 2017, Professor Dr.-Ing. Friedrich Wirz, Hamburg-Harburg University of Technology, Marine Engineering Working Group
- Photographs by Hamburg Police

5 ANNEX

Materials-related testing on a damaged fuel injection valve:

	Untersuchungsbericht Examination report	Nr. 2017/0052 No. Rev. 0 Seite 1/6 Page Datum 15.02.2017 Date
	Bearbeiter: Gross / Surajew Author	
<p>Auftraggeber: Technische Universität Hamburg-Harburg Arbeitsgruppe Schiffsmaschinenbau (M-12) Am Schwarzenberg-Campus 4 21073 Hamburg z. Hd. Herrn Prof. Dr.-Ing. Friedrich Wirz</p> <p>Anlage: MV Cape Leonidas Maschinen-Typ: S70MC-C IMO-Nr.: 9488865 Baujahr: 2010</p> <p>Werkstofftechnische Untersuchung an einem geschädigten Kraftstoffeinspritzventil</p> <p>Vorbemerkungen</p> <p>Am 17. Januar 2017 ereignete sich während eines Motorenbetriebes ein Triebwerksschaden am Hauptmotor des Frachtschiffes MV Cape Leonidas. Bei der ersten Vorort-Schadensbewertung wurde ein nicht intaktes Kraftstoffeinspritzventil vorgefunden. Dieses schadhafte Einspritzventil wurde dann am 27. Januar im Hause der MAN Diesel & Turbo SE / PrimeServ Hamburg einer weiteren Begutachtung unterzogen. Bei der Begutachtung ist das komplette Schadensteil in seine Einzelteile zerlegt worden, wobei ein Verklemmen der Düsennadel im Düsenkörper festgestellt wurde. Diese beiden Bauteile sind danach unter Krafteinwirkung auseinandergenommen worden. Auffällig dabei waren mehrere Oberflächenbeschädigungen im Bereich der Mantelfläche der Düsennadel sowie der Innenbohrung des Düsenkörpers. Diese Oberflächenbeschädigungen sollten laut Auftraggeber durch uns, dem akkreditierten und unabhängigen Werkstoffprüflabor im Hause der MAN, mikroskopisch untersucht werden. Bei der Untersuchung sollte festgestellt werden, ob das Verklemmen der beiden Komponente durch eine thermische Einwirkung oder durch abrasive Fremdpartikel hervorgerufen wurde.</p> <p>Untersuchungsumfang</p> <p>Die schadhafte Oberflächenabschnitte des Düsenkörpers und der Düsennadel wurden mittels Stereo- sowie Raster-Elektronen-Mikroskopie hinsichtlich der Schädigungsart untersucht.</p> <p>Ergebnisse</p> <p>Sowohl der Düsenkörper als auch die Düsennadel sind von Beschädigungen an der Oberfläche gezeichnet (<i>siehe Seite 3</i>). Die Oberflächenbeschädigungen an der Düsennadel wurden im Raster-Elektronen-Mikroskop einer weiteren Untersuchung unterzogen. Dabei konnten keine Anzeichen von Korrosion oder Fremdpartikeln gefunden werden. Alle Einspritzlöcher waren frei von Partikeln und Ablagerungen. Auffällig waren Materialausbrüche an der Manteloberfläche, die höchstwahrscheinlich durch das Verklemmen der beiden Komponenten und dem anschließenden Heraustreiben (Demontage der Komponenten) der Düsennadel aus dem Düsenkörper hervorgerufen wurden (<i>siehe Seiten 4-6</i>). Schlussfolgernd daraus liegt die Vermutung nahe, dass eine thermische Einwirkung zum Verklemmen der beiden Komponenten führte.</p>		
Dipl.-Ing. N. Gross		Distribution list: Technische Universität Hamburg-Harburg MAN Diesel & Turbo SE
<small>Die Prüfergebnisse beziehen sich ausschließlich auf den Prüfgegenstand. Eine auszugsweise Vervielfältigung dieses Prüfberichtes ist ohne schriftliche Genehmigung nicht gestattet. The test results relate exclusively to the test item. Partial reproduction of this test report is not permitted without express approval in writing. Only the original text in German language is authentic.</small>		<small>Durch die Deutsche Akkreditierungsstelle GmbH (DAkkS) akkreditiertes Prüflaboratorium Die Akkreditierung gilt für die in der Urkunde aufgeführten Prüfverfahren</small> 

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Labor_2017.02.01_0043

Anlieferungszustand

Kraftstoffeinspritzventil



Labor_2017.02.01_0044

Markierung am Kraftstoffeinspritzventil


JAN13 353



Labor_2017.02.01_0046

Einspritzventilkomponenten

Düsenkörper und Düsennadel

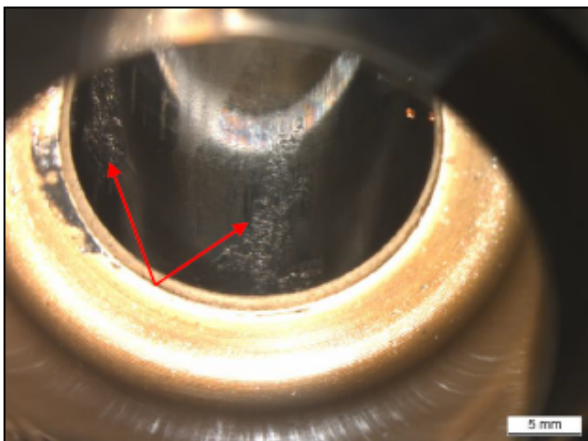
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Labor_2017.02.01_0049

Düsenkörper

Kennzeichnung: 391513050



Labor_2017.02.01_0105

Ansicht A

Die Innenbohrung weist in vier Bereichen Oberflächenbeschädigungen auf.


Oberflächenbeschädigungen, siehe Pfeilmarkierungen



Labor_2017.02.01_0106

Detailvergrößerung

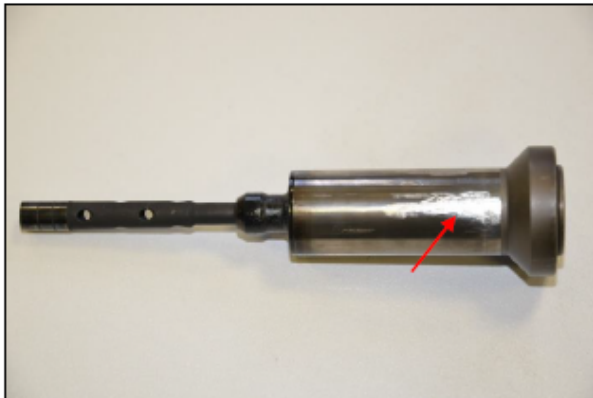
Oberflächenbeschädigungen

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Labor_2017.02.01_0056

Düsenadel

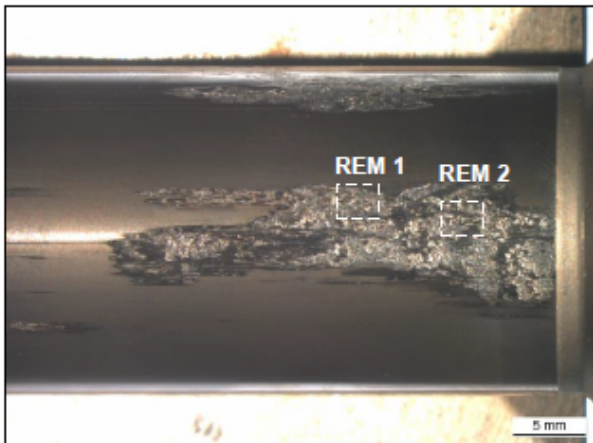


Labor_2017.02.01_0057

Weitere Ansicht

Die Mantelfläche weist in vier Bereichen Oberflächenbeschädigungen auf.

Oberflächenbeschädigungen, siehe Pfeilmarkierungen



Labor_2017.02.01_0107


Detailvergrößerung

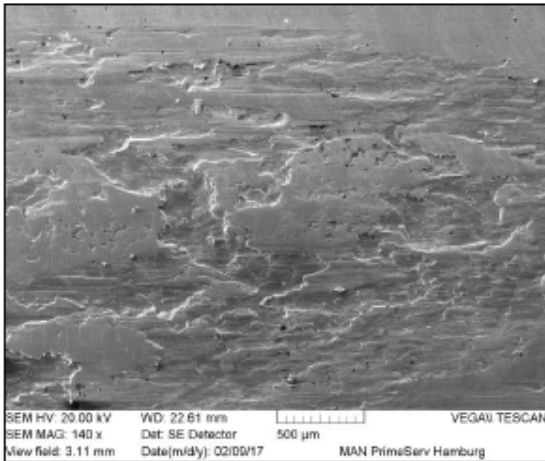
Oberflächenbeschädigungen

REM-Untersuchung der Oberflächenbeschädigungen

REM 1, siehe Seite 5

REM 2, siehe Seite 6

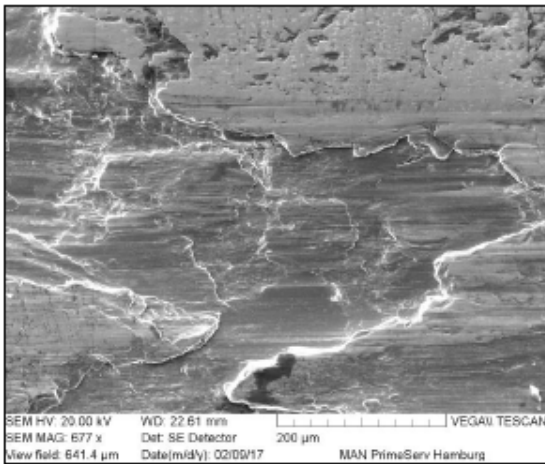
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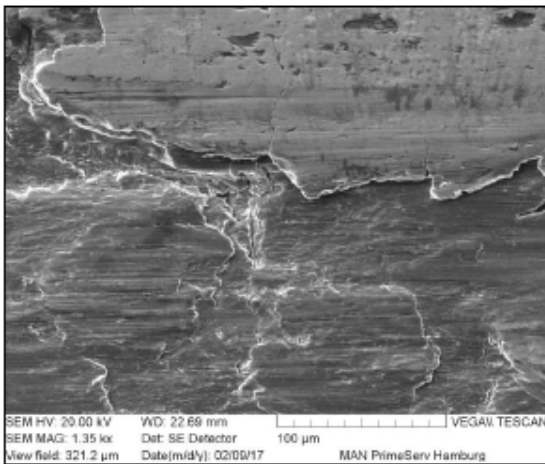
REM-Untersuchung der Oberflächenbeschädigungen

REM 1

Die Mantelfläche weist in diesem Bereich Fressspuren auf.



Detailvergrößerung


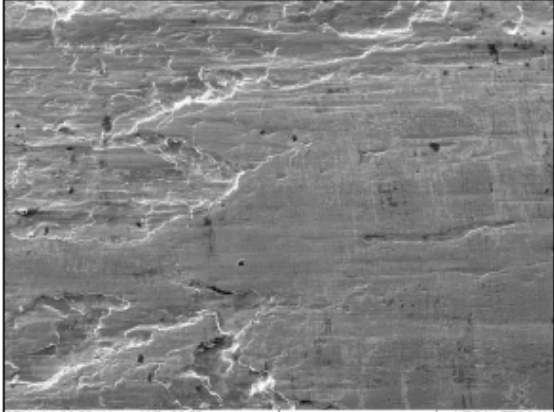
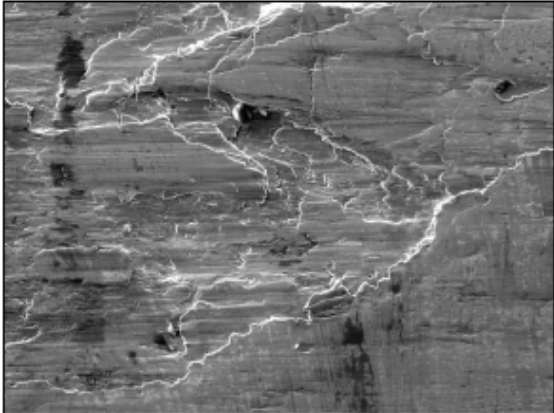
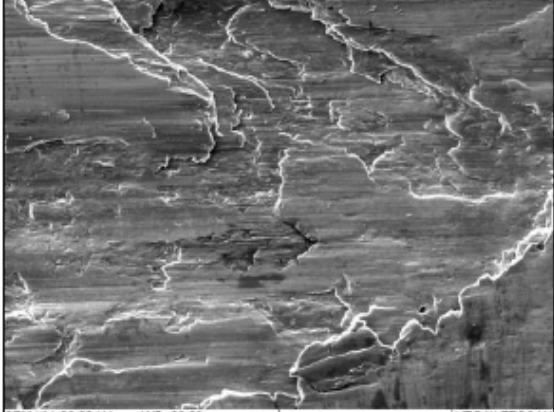


Weitere Detailvergrößerung

Ausgebrochenes Material

Durch das Klemmen der Düsennadel im Düsenkörper und dem anschließenden Heraustreiben (Demontage der Komponenten) der Düsennadel aus dem Düsenkörper hervorgerufene Materialausbrüche.

Abrasive Fremdpartikel auf der Mantelfläche wurden nicht festgestellt.

	<p>Untersuchungsbericht Examination report</p>	<table border="1"> <tr> <td>Nr.</td> <td>2017/0052</td> </tr> <tr> <td>No.</td> <td>Rev. 0</td> </tr> <tr> <td>Seite</td> <td>6/6</td> </tr> <tr> <td>Datum</td> <td>15.02.2017</td> </tr> <tr> <td>Date</td> <td></td> </tr> </table>	Nr.	2017/0052	No.	Rev. 0	Seite	6/6	Datum	15.02.2017	Date	
Nr.	2017/0052											
No.	Rev. 0											
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Datum	15.02.2017											
Date												
 <p>SEM HV: 20.00 kV WD: 22.52 mm VEGAII TESCAN SEM MAG: 249 x Det: SE Detector 500 µm View field: 1.75 mm Date(m/d/y): 02/09/17 MAN PrimeServ Hamburg</p> <p style="text-align: center;">Labor_2017.02.01_D115</p>		<p>REM-Untersuchung der Oberflächenbeschädigungen</p> <p><u>REM 2</u></p> <p>Die Mantelfläche weist in diesem Bereich Fressspuren auf.</p>										
 <p>SEM HV: 20.00 kV WD: 22.70 mm VEGAII TESCAN SEM MAG: 678 x Det: SE Detector 200 µm View field: 640.8 µm Date(m/d/y): 02/09/17 MAN PrimeServ Hamburg</p> <p style="text-align: center;">Labor_2017.02.01_D116</p>		<p>Detailvergrößerung</p>										
 <p>SEM HV: 20.00 kV WD: 22.69 mm VEGAII TESCAN SEM MAG: 1.37 kx Det: SE Detector 100 µm View field: 317.4 µm Date(m/d/y): 02/09/17 MAN PrimeServ Hamburg</p> <p style="text-align: center;">Labor_2017.02.01_D117</p>		<p>Weitere Detailvergrößerung</p> <p>Ausgebrochenes Material</p> <p>Durch das Klemmen der Düsennadel im Düsenkörper und dem anschließenden Heraustreiben (Demontage der Komponenten) der Düsennadel aus dem Düsenkörper hervorgerufene Materialausbrüche.</p> <p>Abrasive Fremdpartikel auf der Mantelfläche wurden nicht festgestellt.</p>										