ACCIDENT REPORT

Report on the investigation of the loss of control and grounding of ro-ro passenger ferry

Hebrides

Lochmaddy, North Uist

Scotland

25 September 2016

SERIOUS MARINE CASUALTY REPORT NO 20/2017 SEPTEMBER 2017

MAIB
MARINE ACCIDENT INVESTIGATION BRANCH

Extract from

The United Kingdom Merchant Shipping

(Accident Reporting and Investigation)

Regulations 2012 – Regulation 5:

"The sole objective of the investigation of an accident under the Merchant Shipping (Accident Reporting and Investigation) Regulations 2012 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."

<u>NOTE</u>

This report is not written with litigation in mind and, pursuant to Regulation 14(14) of the Merchant Shipping (Accident Reporting and Investigation) Regulations 2012, shall be inadmissible in any judicial proceedings whose purpose, or one of whose purposes is to attribute or apportion liability or blame.

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GLOSSARY OF ABBREVIATIONS AND ACRONYMS

CFL	-	CalMac Ferries Limited
CMAL	-	Caledonian Maritime Assets Limited
CPP	-	Controllable pitch propeller
DML	-	David MacBrayne Limited
ECR	-	Engine control room
kts	-	knots
MVOM	-	Major Vessels Operations Manual
OEM	-	Original Equipment Manufacturer
RR Marine	-	Rolls-Royce Marine
STCW	-	The International Convention on Standards of Training, Certification and Watchkeeping for Seafarers 1978, as amended
UTC	-	Universal co-ordinated time

TIMES: all times used in this report are UTC(+1) unless otherwise stated

SYNOPSIS

On 25 September 2016, the ro-ro passenger ferry *Hebrides* was approaching Lochmaddy, North Uist, Scotland when control of the ferry's port controllable pitch propeller was lost. The master attempted to control the ferry's movements but he was unable to prevent it from running over several mooring pontoons and briefly grounding. There were no injuries among the passengers and crew but the ferry was damaged and had to be taken out of service and repaired in dry dock.

The MAIB investigation identified that:

- The loss of control was caused by a mechanical failure within a linear servomotor actuator in the propulsion control system.
- The mechanical failure resulted from a setscrew not being secured in position with thread locking compound when it was replaced 6 months earlier.
- Neither the service engineer who fitted the setscrew nor the ferry's engineers who subsequently inspected the actuator were aware of the actuator manufacturer's service instruction to secure the setscrew with thread locking compound.
- Upgrades to the propulsion control system that had been recommended by its supplier to mitigate the consequences of a propeller control failure had not been implemented.
- The crew's response to the loss of control was well intended but was un-coordinated because they were not sufficiently prepared or practised to deal quickly and effectively with the loss of pitch control in the confined waters.

A recommendation has been made to Rolls-Royce Marine, the provider of the propulsion control system fitted on board *Hebrides*, aimed at ensuring that service instructions are made available to service engineers and in documentation provided to vessels. A recommendation has also been made to CalMac Ferries Ltd, the ferry's operator, which is intended to ensure that recommendations for safety critical system upgrades received from manufacturers are properly documented and processed and that its crews are better prepared to deal effectively with propulsion failures.

SECTION 1 - FACTUAL INFORMATION

1.1 PARTICULARS OF *HEBRIDES* AND ACCIDENT

SHIP PARTICULARS	
Vessel's name	*Hebrides*
Flag	UK
Classification society	Lloyd's Register
IMO number/fishing numbers	9211975
Type	Ro-ro passenger ferry EU class B
Registered owner	Caledonian Maritime Assets Ltd
Manager(s)	CalMac Ferries Ltd
Construction	Steel
Year of build	2001
Length overall	99.4m
Gross tonnage	5506
Minimum safe manning	24
Authorised cargo	Not applicable
VOYAGE PARTICULARS	
Port of departure	Tarbert, Isle of Harris
Port of arrival	Lochmaddy, North Uist
Type of voyage	Domestic passenger
Draught	2.85m forward and 3.3m aft
Cargo information	14 vehicles
Manning	32 crew
MARINE CASUALTY INFORMATION	
Date and time	25/09/2016 at 1029
Type of marine casualty or incident	Serious Marine Casualty
Location of incident	Lochmaddy harbour
Place on board	Engine room/hull
Injuries/fatalities	None
Damage/environmental impact	Indentations below the waterline; damaged propeller blade and stern tube outer seal. Approximately 200l of hydraulic oil was leaked overboard.
Ship operation	On passage
Voyage segment	Transit (port entry)
External environment	Wind Beaufort Force 6
Persons on board	32 crew 45 passengers

1.2 NARRATIVE

1.2.1 Passage

During the morning of 25 September 2016, the passenger ro-ro ferry *Hebrides* was on passage from East Loch Tarbert, Isle of Harris, to Lochmaddy, North Uist **(Figure 1)**. On board the ferry were 32 crew, 45 passengers and 14 vehicles. The third officer was the officer of the watch accompanied by a quartermaster on the helm. The ferry's propulsion was being controlled from the bridge's centre console **(Figure 2)**. Both the port and starboard controllable pitch propellers (CPP) were set to 100% ahead and the ferry was making good 14 knots (kts)[1]. The visibility was moderate and the wind was gale force from the south-south-west. The sea was rough with a moderate swell.

1.2.2 Approach to Lochmaddy

At 1017, *Hebrides*'s master arrived on the bridge and took the con from the third officer. The chief officer and the second officer were also on the bridge preparing for the forthcoming disembarkation and embarkation, but they were not part of the navigational watch. In view of the wind conditions, the master decided to approach Lochmaddy from the north-east[2]. At 1020, *Hebrides* was 3.25nm from the pier roundhead in Lochmaddy and standby was rung on the bridge engine movement telegraph[3]. The master reduced the pitch on both CPPs to 80% ahead.

At 1028, *Hebrides* was making good a course of 265° at 12.9kts and the master further reduced the pitch on the CPPs to 60% ahead. One minute later, as the ferry passed to the north of Ruigh Laith light **(Figure 3)**, the master moved to the starboard wing console and set both CPPs to just over 40% pitch ahead. He then pressed the 'common in command' button **(Figure 4)** to transfer control of the CPP, shaft clutches and bow thrusters from the centre to the starboard wing console. The master monitored the CPP pitch indicators on the starboard wing console and saw the pitch on both propellers start to reduce from 60% ahead. The reduction in pitch was also observed by the third officer at the centre console. The master was satisfied that the transfer of pitch control had been successful and also transferred control of the steering and bow thruster to the starboard wing console. The quartermaster was no longer required on the helm, so he washed the bridge windows using an internally activated tap system and then left the bridge.

1.2.3 Loss of control

At 1031, *Hebrides* was heading 230° at 10.4kts **(Figure 5)**. The master set the port CPP to 0% and then to 70% astern. In accordance with his usual practice the master did not look at the pitch indicators because he had already established that he had control at the starboard wing console. However, he soon noticed that the ferry's speed was not reducing as quickly as he expected, and set the starboard CPP to 0% pitch.

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1 All speeds and courses in this report are 'over the ground'.

2 Two navigable channels are available for entry to Lochmaddy, the central channel and the south channel. The central channel approaches from the north-east and is used by ferries in strong winds from the south-west and north-east to enable landing head or stern to wind on the pier roundhead before berthing at the linkspan.

3 'Standby' is a heightened state of readiness adopted by a vessel's bridge and engine room crew when operating in confined or congested waters, such as when entering and leaving harbour.

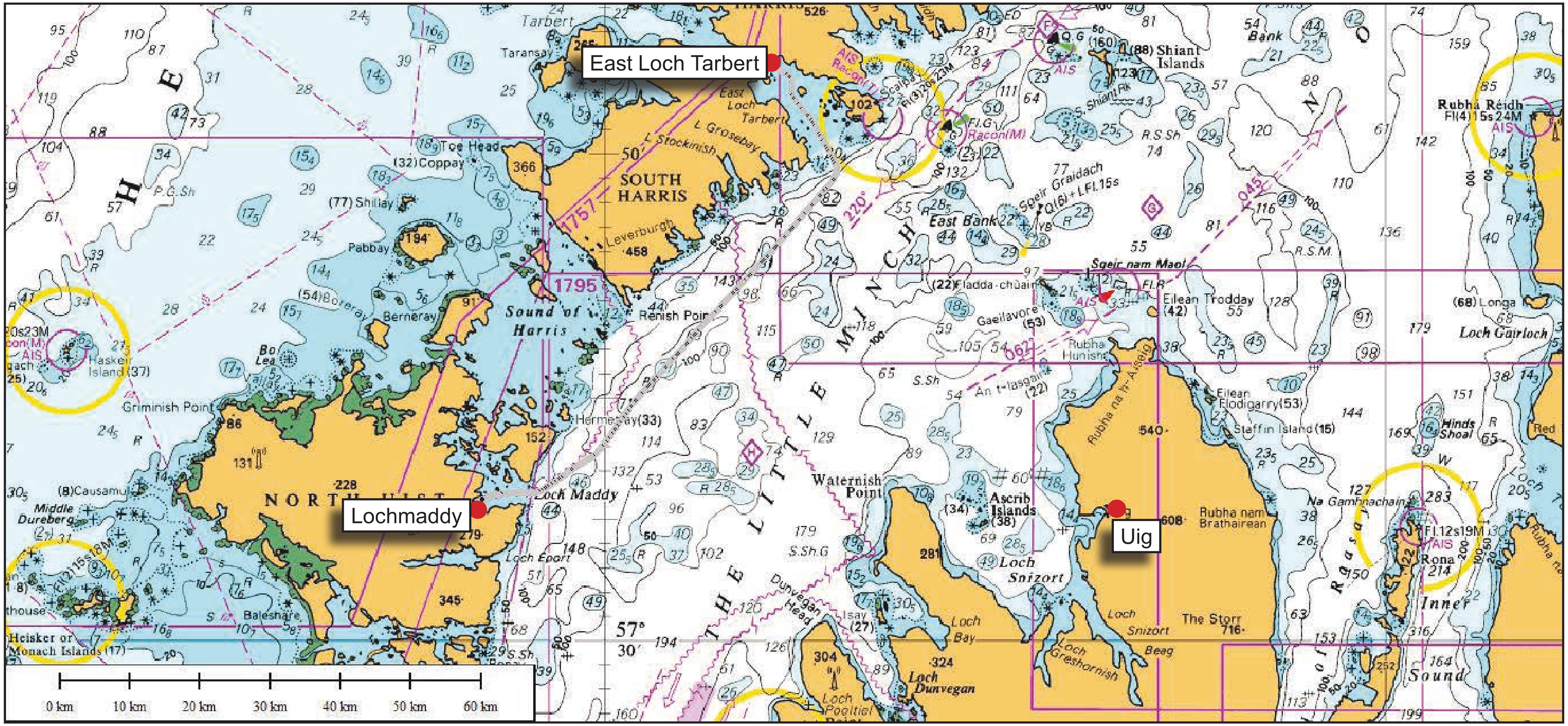

Figure 1: Extract of chart BA 2635-0 showing the position of Lochmaddy

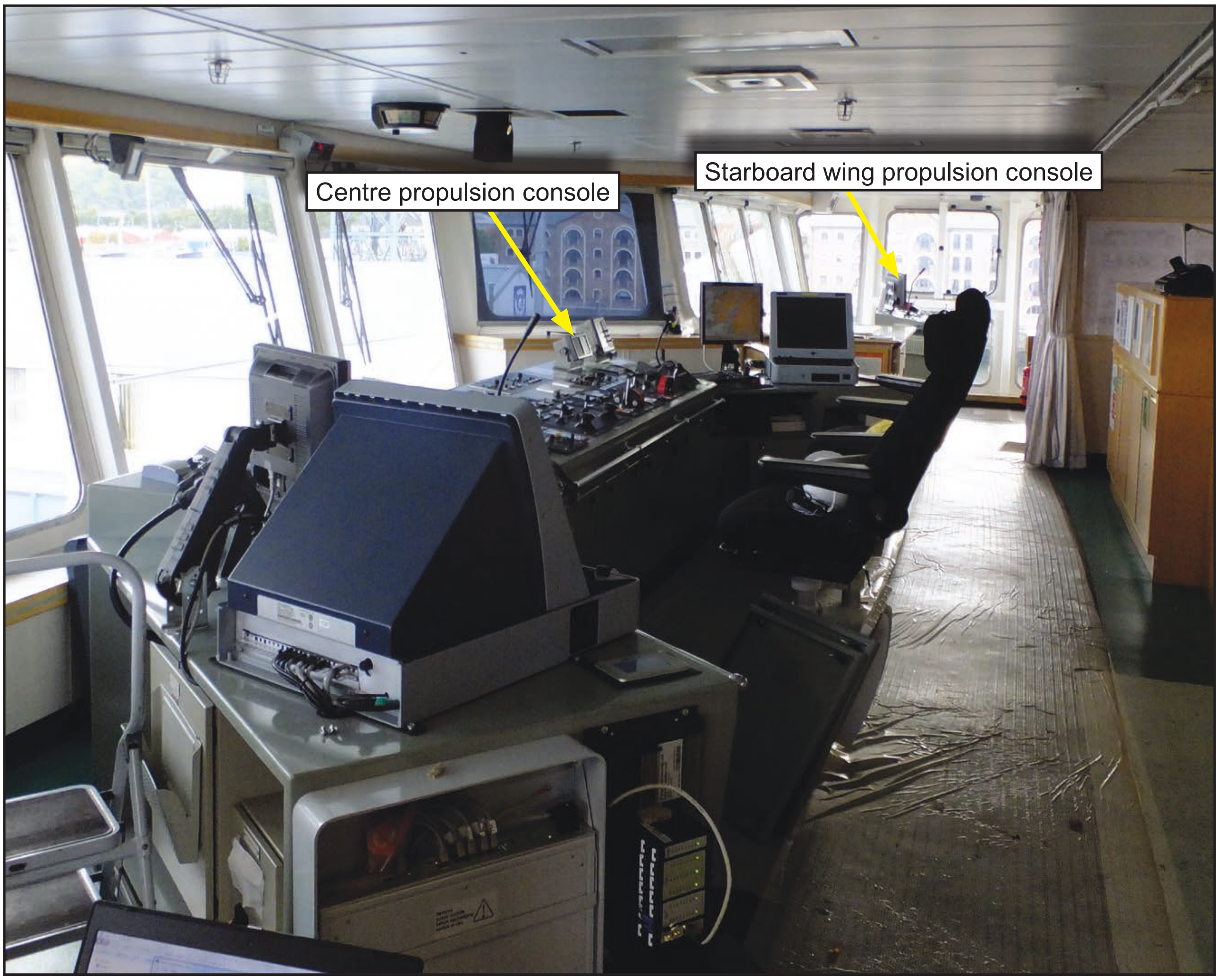

Figure 2: Bridge layout

The master initially thought that *Hebrides*'s slow response to the pitch adjustments was possibly due to the ferry's trim. He commented to the third officer that the ferry's speed was still 10kts and asked him to check the stability data. As the third officer checked the data, he looked at the CPP indicators on the centre console and saw that the pitch on the port CPP was at 50% ahead. He immediately told the master, who set both the port and starboard CPPs to 100% pitch astern. The starboard CPP pitch moved to 100% astern but the port CPP pitch remained at 50% ahead. The ferry was now less than 200 metres off the pier roundhead, and its bow soon started to swing to starboard. To counteract the swing, the master set the bow thrusters to 100% thrust bow to port. It is not known if port helm was also used. The master assessed that the astern power on the starboard shaft would eventually stop the ferry, but he was uncertain how long, or how much sea room this would take. The master discounted the use of the anchors to slow the vessel in view of the relatively high speed and the risk to the forward mooring party.

Meanwhile, the second officer, who had been working at the back of the bridge with the chief officer, telephoned the ECR and informed the second engineer on watch that the port CPP was "stuck ahead". The second engineer relayed the message to the chief engineer, third engineer and extra third engineer, who were in the ECR. He also asked the second officer if the bridge team had attempted to use the

Reproduced from Admiralty Chart BA 2825-1 by permission of the Controller of HMSO and the UK Hydrographic Office

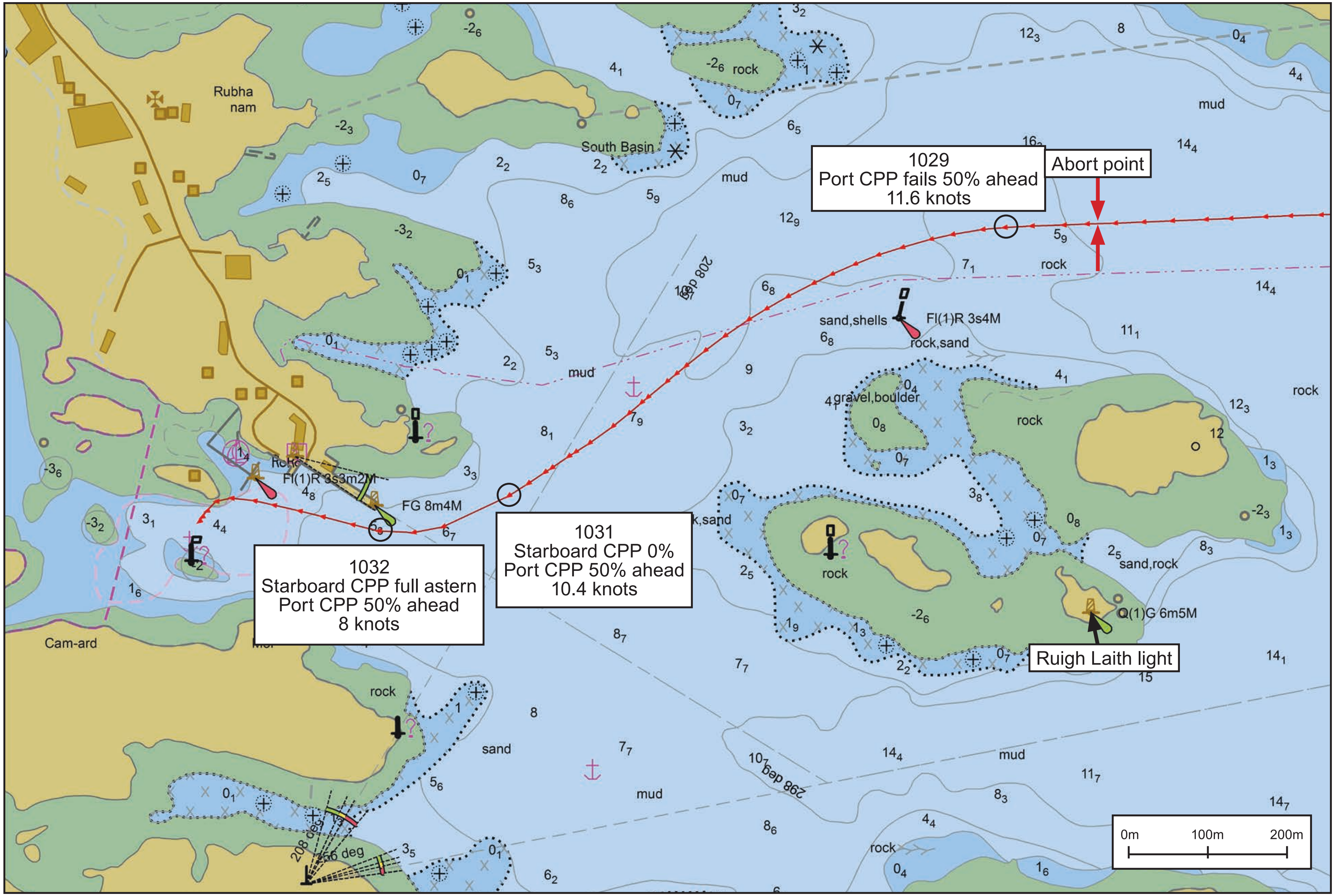

Figure 3: Approach to Lochmaddy

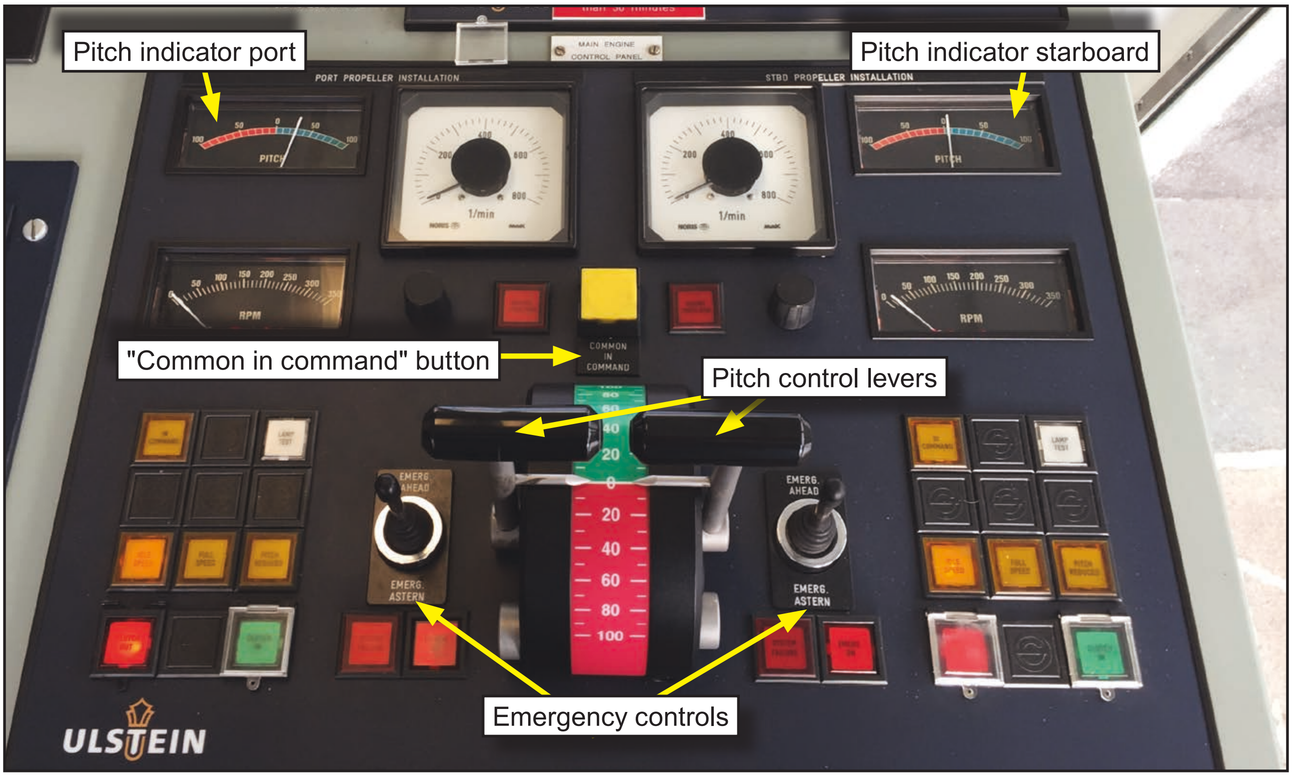

Figure 4: Propulsion control panel (starboard console)

emergency pitch control. In response, the second officer prompted the master to engage the emergency pitch control, which he did, but without success. The bridge team were reported to be in an increasing state of panic.

In the ECR, the third engineer transferred control of the port CPP from the bridge to the ECR control console, which was indicated by an audible signal on the bridge. He then attempted to reduce the port CPP pitch to zero; it remained at 50% ahead. On seeing this, the chief engineer went to the engine room to place the port CPP into local control. As he left the ECR, the chief engineer told the extra third engineer to provide him with a radio. Meanwhile, the second engineer started the two main diesel generators and transferred the ship's electrical power from the port shaft generator to the diesel generators.

1.2.4 The grounding

At 1032, *Hebrides*'s speed was about 8kts. The swing to starboard had been arrested and the ferry was approximately 30m to the south of the pier, making good a course of about 280° towards a set of mooring pontoons **(Figure 5)** 70m ahead. At about this time, the chief engineer set the port CPP pitch to 0° using a lever on the port shaft gearbox **(Figure 6)**. He also tried to attract the bridge team's attention by moving the local engine telegraph. The telegraph alarm was audible on the bridge, but it was ignored.

The third officer prompted the master to de-clutch the port shaft. The master depressed the port shaft 'clutch-out' button on the starboard wing console **(Figure 4)** several times, accidentally breaking the button's protective cover as he did so. However, the port shaft remained clutched in. The master was not aware that the ECR had taken control of the port CPP or that the chief engineer had set the port

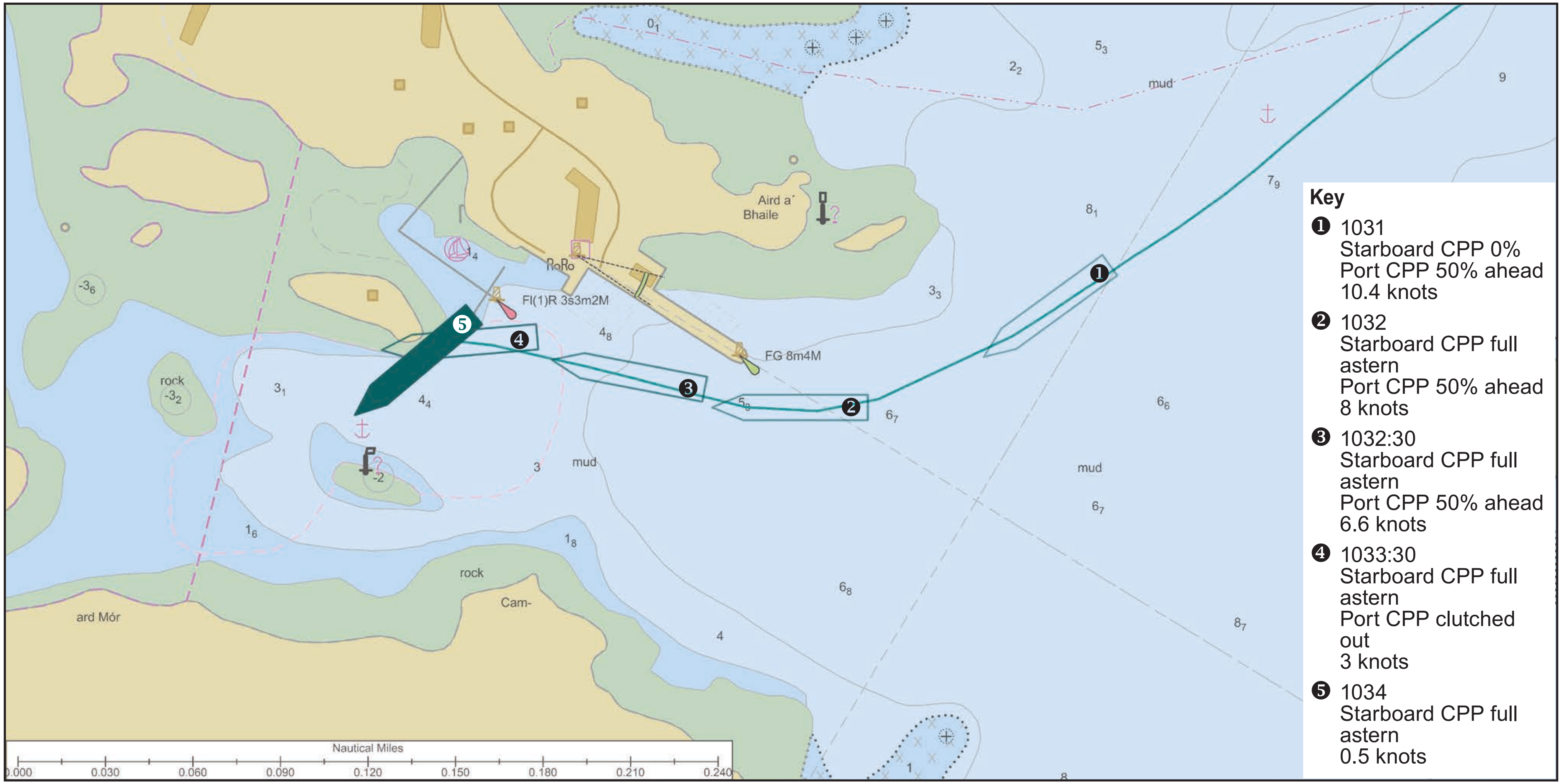

Figure 5: Track following loss of control

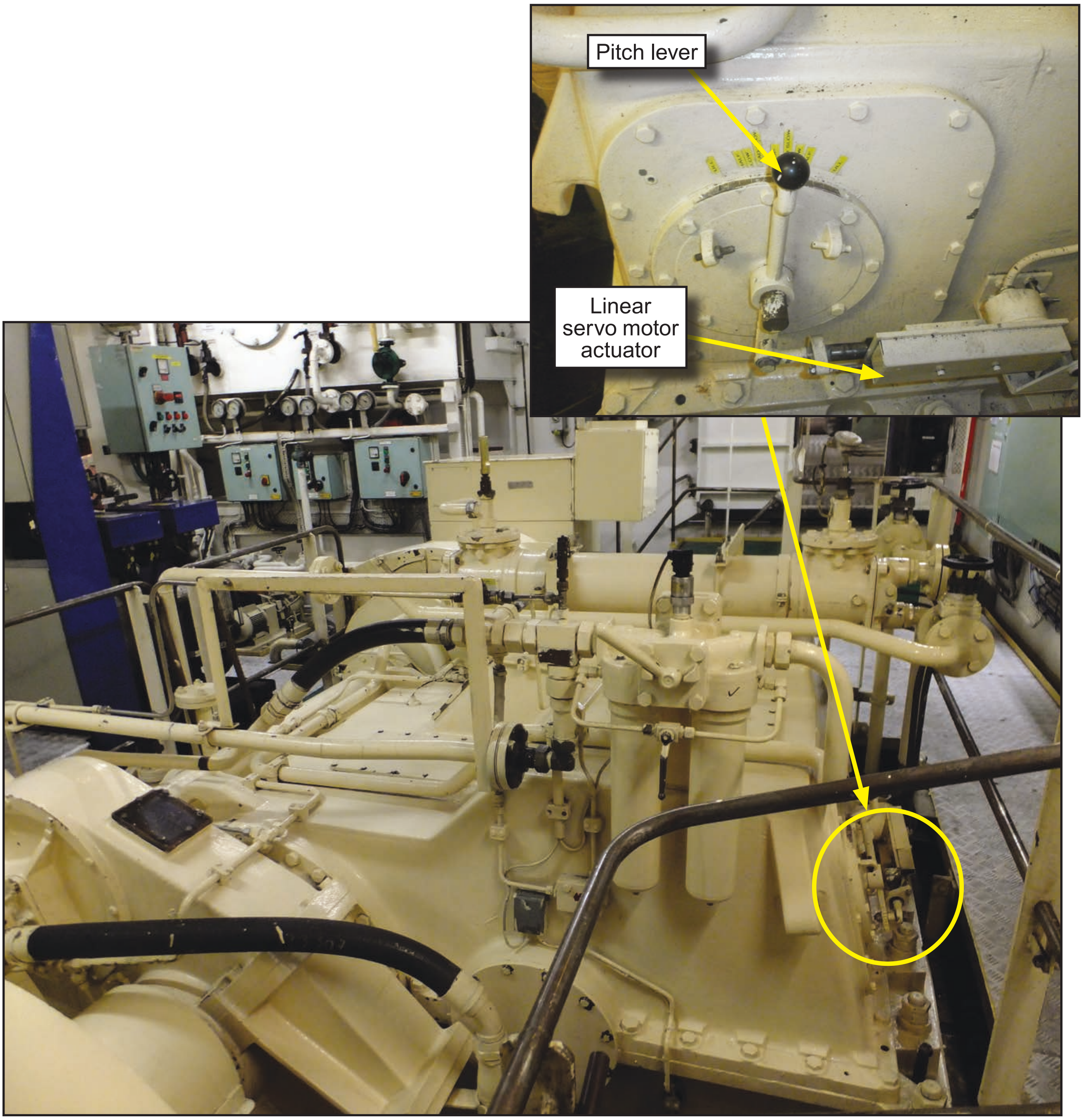

Figure 6: Port gearbox

CPP pitch to 0˚. The chief engineer had been provided with a radio headset and throat microphone but his transmissions were not heard by the bridge team due to the background noise in the engine room.

At 1033, the second officer transferred control of the port CPP from the ECR to the bridge's centre console. With the master's approval, he then pressed the port shaft 'clutch-out' button and the shaft de-clutched and stopped rotating. The master saw that the port shaft had de-clutched and again pressed the 'in command' button on the starboard wing console. He also continued to use the bow thrust to turn the ferry away from the linkspan towards safe water to the south. Meanwhile, the chief engineer saw the port shaft had stopped rotating and returned to the ECR.

Hebrides's speed was now 5kts and the ferry's bow was swinging to port. As it did so, it ran over the outer mooring pontoons, causing some of the pontoons to overturn. Seconds later, at 1034, the ferry gently grounded and stopped in the water **(Figures 5** and **7)**.

Photograph courtesy of Scottish TV News

Figure 7: *Hebrides* aground

1.2.5 Post-grounding

Hebrides's starboard CPP remained at 100% pitch astern and the bow thrusters remained at 100% thrust to port. Within 30 seconds of grounding, the ferry started to move astern and its bow resumed the swing to port. Moments later, at 1036, the ferry backed over the upturned pontoons **(Figure 8)**. A loud continuous banging noise was then heard coming from towards the stern and the starboard stern tube oil header tank low level alarm activated in the ECR.

The master ran to the port bridge wing and transferred control of the CPPs and shaft clutches to the port wing console. He then attempted to manoeuvre *Hebrides* alongside, port side to the pier. When the ferry was close to, and almost parallel with the pier, the master clutched-in the port shaft and the ferry quickly gathered headway. The chief engineer saw that the port shaft was again clutched-in with ahead pitch set. He returned to the port gearbox ready to take local control of the port CPP. The master was reluctant to manoeuvre the ferry alongside with the port CPP in local control so he clutched-out the port shaft.

As *Hebrides* moved ahead at a speed of 3kts, the rubbing strake on the ferry's port side made heavy contact with the pier's fendering. The master then manoeuvred *Hebrides* into safe water to the east, where the chief officer and the ship's carpenter sounded the ferry's void spaces and tanks. No water ingress was identified. An announcement was made on the public address system to advise the passengers of

Photograph courtesy of Ben Wear

Figure 8: *Hebrides* backing over mooring pontoons

the situation and to return to their seats and await further instructions. At 1059, the master manoeuvred *Hebrides* alongside the quay in Lochmaddy (bows west). The port shaft remained 'clutched-out' and was not used during the berthing.

1.3 DAMAGE

Several mooring pontoons in Lochmaddy were upturned and damaged **(Figure 9)**. The hull plating along *Hebrides'*s starboard side above the flat bottom was indented and the ferry's starboard bilge keel was distorted **(Figure 10)**. A length of mooring chain was also found wrapped around the starboard propeller shaft, which had damaged the outer stern tube seal and propeller **(Figure 11)**.

1.4 REPAIR

While *Hebrides* was alongside in Lochmaddy, the ferry's engineers inspected a linear servomotor actuator sited on the port gearbox **(Figure 6)**. The servomotor converted electrical signals from the control consoles into mechanical motion, which ultimately adjusted the pitch of the propeller blades. The conversion was achieved by an electric stepper motor rotating a shaft that moved a linkage rod via a ball screw mechanism. When

Photograph courtesy of CFL

Figure 9: Upturned pontoons

Photographs courtesy of CFL

Figure 10: Damage to starboard bilge keel and hull bottom

Photograph courtesy of CFL

Figure 11: Mooring chain around starboard propeller

the engineers released the stepper motor from the servomotor assembly, it was apparent that a jaw coupling on the motor's shaft had loosened. The setscrew securing the coupling to the flat surface on the stepper motor's 'D' shaped shaft had backed off to the extent that the stepper motor shaft could be withdrawn without disturbing the coupling **(Figure 12)**. See paragraph 1.7 for a description and detail of the actuator.

Hebrides's engineers, assisted by a service engineer from Rolls-Royce Marine (RR Marine), the original equipment manufacturer (OEM) for the propulsion control system, effected a temporary repair to make the actuator usable. The repair included using thread locking compound to secure the setscrew in place.

With the approval of the Maritime and Coastguard Agency and Lloyd's Register, *Hebrides* sailed from Lochmaddy on 29 September 2016 for passage to Garvel dry dock on the Clyde for permanent repair. Only the port shaft was used during the voyage. While *Hebrides* was undergoing repair in Garvel, RR Marine replaced the linear servomotor actuator on the port gearbox.

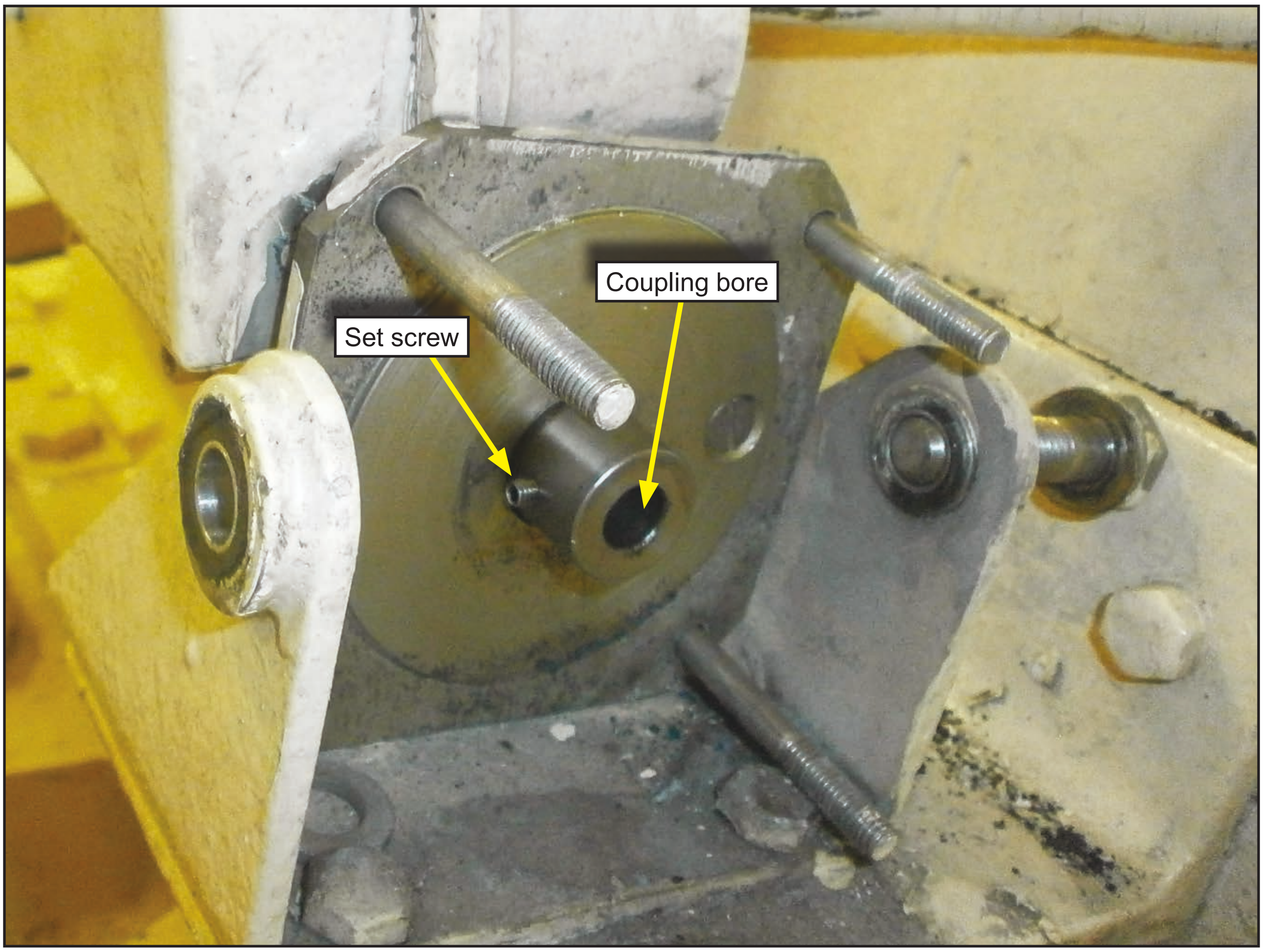

Figure 12: Position of jaw coupling setscrew (as found)

1.5 TECHNICAL ANALYSIS

In January 2017, RR Marine passed the linear servomotor actuator that had been removed from *Hebrides* to its air safety investigation workshop for analysis. The analysis **(Annex A)** identified that the 'cone' point of the setscrew had not penetrated the stepper motor's shaft and had deformed under load **(Figure 13)**. It also identified that the setscrew did not have any practical rundown torque[4]. The markings on the shaft indicated that the shaft had moved within the coupling prior to complete failure **(Figure 14)** and that a cup-pointed setscrew, not a cone-pointed setscrew, had originally been used in the assembly.

[4] Rundown torque is the force required to overcome the resistance to rotational movement of the setscrew.

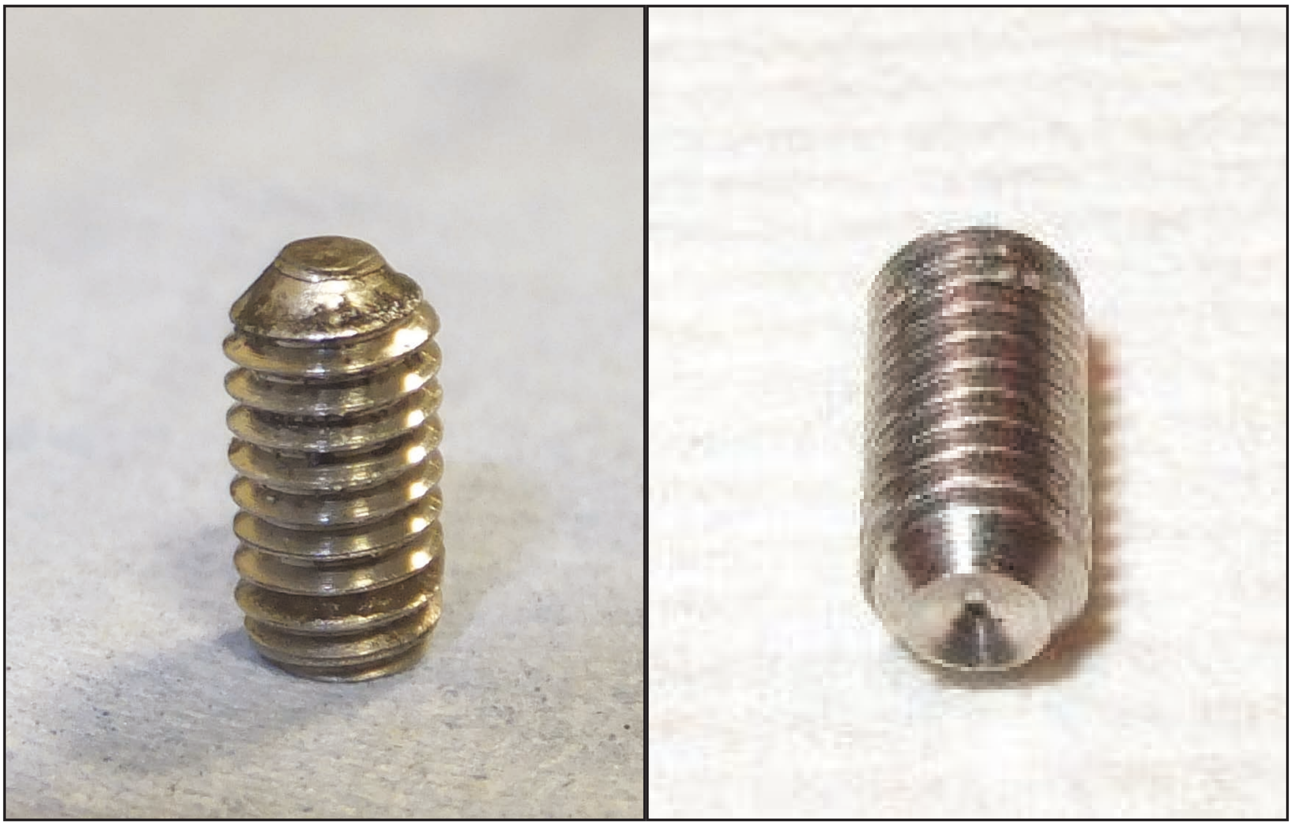

Figure 13: Deformed ‘cone’ pointed set screw and a ‘cup’ pointed setscrew

Figure 14: Marks on stepper motor shaft

1.6 VESSEL

1.6.1 Ownership and management

Hebrides was built in 2001 and was used to provide a ferry service between Tarbert (Isle of Harris), Lochmaddy (North Uist) and Uig (Isle of Skye) **(Figure 1)**. The ferry was owned by Caledonian Maritime Assets Ltd (CMAL), which leased it to CalMac Ferries Ltd (CFL), a subsidiary of David MacBrayne Ltd (DML). CFL was responsible for the ferry's repair and maintenance but CMAL retained responsibility for capital expenditure items including upgrades to machinery and systems. CFL operated a fleet of 34 ferries, of which *Hebrides* was one of 14 ferries designated by the operator as a 'major vessel'. Both CMAL and DML were owned by the Scottish Government.

1.6.2 Crew

<u>General</u>

Hebrides had 32 crew on board. All members of the bridge and ECR teams held the STCW[5] certificates of competency required for their positions on board. They also met the Convention's requirements concerning hours of work and rest. The crew typically worked from 0600 to 1800 daily.

<u>Bridge team</u>

The master was 58 years old and had been employed by CFL for over 21 years. He had worked on board ferries operating the Western Isles routes for 16 years, 8 of which had been on board *Hebrides*. It was usual practice for the master to con the vessel for both arrival and departure, assisted by the nominated officer of the watch.

The chief officer was 38 years old and had been employed by CFL for 3 years, the last 2 years as the relief chief officer on board *Hebrides*. The second officer was 39 years old and had been employed by CFL for 13 years and had worked on board *Hebrides* for the last 3 years. The third officer was 21 years old and was employed by CFL on a seasonal contract. He had worked on board *Hebrides* for 6 months.

Following the accident, the bridge team were tested for alcohol using onboard equipment; the tests were negative.

<u>ECR team</u>

The chief engineer was 58 years old and had been employed by CFL for 17 years, 6 of which he had worked on board *Hebrides*. The second engineer was 41 years old and had been employed by CFL for 8 years. He had worked on board *Hebrides* for 9 months. The third engineer was 41 years old and had been employed by CFL for 5 years, 4 of which he had worked on board *Hebrides*. The extra third engineer was 32 years old and had been employed by CFL on a seasonal contract. He joined *Hebrides* the day before the accident.

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5 STCW - The International Convention on Standards of Training, Certification and Watchkeeping for Seafarers.

1.7 PROPULSION AND PROPULSION CONTROL

1.7.1 Propulsion

Hebrides's propulsion comprised twin shafts fitted with CPPs and powered by MaK 8 M32 engines through single reduction gearboxes with shaft generator power take-offs. The oil distribution system used to adjust the pitch of the propeller blades was integral to the gearboxes. The ferry was equipped with twin high lift rudders and twin bow thrusters and had a service speed of 16.5kts.

1.7.2 Primary remote control

Hebrides was fitted with a HeliconX propulsion remote control system manufactured by RR Marine that enabled the ferry's propulsion to be operated from the bridge or the ECR. The bridge's propulsion control panels were sited on the centreline and the port and starboard wing consoles **(Figure 2)**. The control functions on the panels included pitch adjustment, clutch engagement/disengagement, emergency control and transfer of the 'in command' position. The control panels were also fitted with several warning and indicator lamps **(Figure 4)**. The control panel in the ECR was similar to the bridge panels except pitch control was via knurled wheels rather than levers.

The transfer of control between the bridge control panels was initiated by pushing the 'common in command' button on the panel taking control. Transfer of control between the bridge and the ECR was initiated by pressing the 'man change' button on the centre console on the bridge or in the ECR.

1.7.3 Emergency remote control

If the primary control system failed a secondary system could be selected by pressing the 'emergency control' button on any of the three bridge panels **(Figure 4)**. The pitch and direction set on the CPPs was then adjusted by joy sticks. A warning indicator lamp illuminated on the bridge panel in control and on the ECR panel when the emergency control had been selected.

1.7.4 Local control

The pitch and direction of the CPPs could also be controlled 'manually' (or 'locally') via the movement of operating levers on the gearboxes **(Figure 6)**; this method was used regularly to test the CPP systems during start-up checks. To use the levers, remote control was disconnected by setting an adjacent switch to 'local'. However, the manual adjustment of the lever overrode remote operation even when 'local control' was not selected.

Engine telegraph repeaters were fitted by the gearboxes through which required pitch settings could be ordered from the bridge. There were no fixed methods of voice communication between the local control position and the ECR or the bridge.

1.7.5 Control system upgrades

In May 2013, RR Marine issued a service letter **(Annex B)** that recommended the upgrading of HeliconX propeller control systems to incorporate a pitch deviation alarm to alert operators when there was a discrepancy between pitch demanded and pitch achieved. The letter also included the option of a further upgrade to provide automatic clutch-out functionality in the event of a pitch deviation. The letter indicated that the upgrades had been incorporated in later systems and their implementation would take between 1 and 2 days.

No record of RR Marine's service letter was found in CFL's technical department, which was not aware of its recommendations. The company did not have a procedure in place for dealing with information received from OEMs related to equipment and machinery fitted on board its vessels.

In 2015, RR Marine revised its service letter process to make safety related issues easier to recognise by its customers.

1.8 ACTUATOR

1.8.1 Description

The linear servomotor actuator on the port gearbox **(Figure 6)** was supplied by Scana Mar EL (Scana) to RR Marine as a complete unit. It comprised a stepper motor and ball screw unit connected by a flexible jaw coupling. The jaw coupling comprised two halves, each with two protruding spigots that interlocked when the two halves of the coupling were engaged **(Figure 15)**. The interlocked spigots were kept spaced evenly apart by an elastomer insert known as a spider, which absorbed torsional vibration and prevented backlash.

The coupling was based on a common design but was specifically adapted by Scana for use in the actuator. The half coupling connected to the stepper motor D shaft was plain bored. The machining tolerance for the coupling bore was 9.55mm H7, which gave a maximum clearance between the stepper motor shaft and coupling bore of 0.03mm. A hole perpendicular to the centreline of the bore was tapped through the coupling half to take an M4 setscrew **(Figure 12)**. The H4 setscrews used by Scana met the requirements of DIN916 (the international standard for setscrews), that specifies that one end of the setscrew is to be a 'cup' point **(Figure 13)**.

The actuator's components were sourced from several manufacturers and were assembled by Scana. The assembly process included locating the jaw coupling on the stepper motor shaft and locking it in place by tightening of the setscrew. To ensure that the setscrew remained secured in place, thread locking compound was used.

The actuator had been in production for 20 years and over 2000 units were in use in various applications. No previous incidents had been recorded where failure of the actuator had been due to a loose setscrew.

1.8.2 Service instructions

The job description for the inspection of the actuator, written by Scana, is at **Annex C**. The instructions recommended annual inspection of the jaw coupling to check for, among other things, the security of the setscrew and wear or damage to the elastomer spider. The instructions also indicated that thread locking fluid was to be used to secure the coupling setscrew. The suggested service life of the actuator was 15000 hours in operation (subject to the replacement of worn parts).

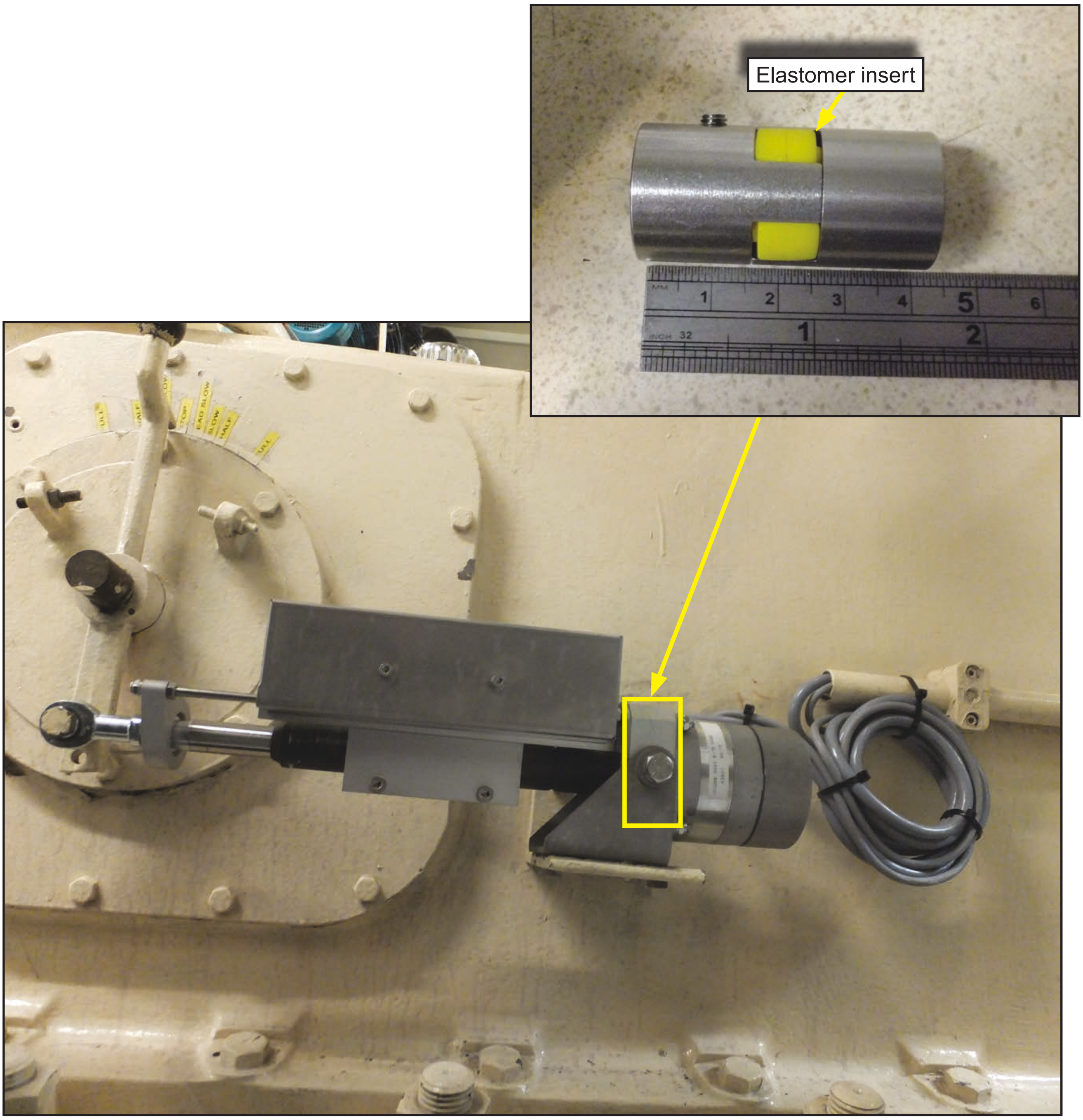

Figure 15: Linear servomotor actuator (with jaw coupling)

The service instructions for the actuator were not included in the system's engineering manuals carried on board *Hebrides* that had been provided by RR Marine. Furthermore, RR Marine had not issued any information regarding the maintenance or inspection of the actuator.

1.8.3 Coupling failure in July 2015

In July 2015, problems were experienced with the control of *Hebrides*'s port CPP. The ferry's engineers took the actuator on the port gearbox apart and found that the elastomer spider in the jaw coupling had disintegrated. The actuator had completed approximately 55000 hours in operation and the coupling had not been inspected since its installation. Following temporary repair with a locally sourced spider, permanent repair was completed in August 2015 with the insertion of a spider supplied by RR Marine. The ferry's planned maintenance system was also amended to include an annual inspection of the jaw coupling.

1.8.4 Coupling replacement in March 2016

As a precautionary measure, CFL arranged for RR Marine to replace the jaw couplings in both the port and starboard actuators on board *Hebrides*. The work was completed in March 2016 by an RR Marine service engineer using parts provided by RR Marine. The service engineer was experienced in working with the HeliconX control system but he had never previously dissembled and reassembled an actuator. He was also not aware of the instructions provided by Scana regarding the inspection of the actuator **(Annex C)**. No other service information was available.

When the RR Marine service engineer replaced the coupling in the actuator on the port gearbox, he was unable to remove the half coupling on the ball screw shaft. However, the ball screw coupling appeared to be in a satisfactory condition so the engineer replaced only the half coupling on the stepper motor shaft and the spider. To do this, the engineer had to drill out the bore of the half coupling to make it fit onto the stepper motor shaft. The half coupling was then secured to the stepper motor shaft by the engineer tightening the setscrew. No thread locking fluid was used on the setscrew during re-assembly.

1.8.5 Inspection in July 2016

In July 2016, the couplings in the port and starboard actuators were inspected in accordance with the onboard planned maintenance system with the focus being on the condition of the spider. The coupling had been in service for approximately 1200 hours since being installed in March 2016. During the inspection the stepper motor part of the coupling was not removed from its shaft. Inspection notes indicated that the coupling was in very good condition and no defects were identified.

1.9 ONBOARD PROCEDURES

1.9.1 Emergency response

Procedures on board *Hebrides* were specified in the Major Vessels Operations Manual (MVOM) that CFL issued to all its vessels. Included in the MVOM was the 'Master's Decision Support System' comprising flow tables on printed cards to assist masters in emergency situations including fire, flooding, grounding and critical equipment failure. The card covering 'critical equipment failure' is at **Annex D**. The MVOM also included: *All critical systems necessary for berthing the vessel should be verified as working satisfactorily before the "Abort Position" is reached, and this should be confirmed as such on the arrival checklist.*

Risk assessment on board *Hebrides* had identified a need to develop a contingency plan to operate the CPP manually from the gearbox in the event of a CPP control failure. However, a contingency plan was not developed.

1.9.2 Arrival

Checklists were used on board *Hebrides* to assist the bridge and ECR teams in ensuring that equipment critical to the ferry's safe navigation was available and functioning correctly before entering port. The checklists were developed with input from seafarers as part of an initiative introduced by CFL in August 2016. These were intended to improve bridge standards and reduce accidents and near misses. During *Hebrides*'s passage to Lochmaddy on 25 September 2016, the arrival checklist had been completed prior to the ferry passing the planned abort position north of Ruigh Laith light **(Figure 3)**.

A pre-condition for arrival was the establishment of a 'Red Zone' on the bridge, which had to be enforced on passing the planned 'abort position'. The introduction of the 'Red Zone' concept was intended to help ensure that distractions to the bridge team - such as communications - were minimised, and that the team could focus on navigation.

1.10 ONBOARD DRILLS

Hebrides's crew routinely conducted training drills in accordance with various regulatory requirements. These included a 3-monthly emergency steering drill, and electrical blackout and steering failure, conducted every 6 months in conjunction with an engine room fire drill. No drills were conducted related to the loss of CPP control or propulsion failure.

1.11 TRAINING IN RESOURCE MANAGEMENT

Since about 2006, CFL had arranged for its senior seagoing officers to attend a 5-day crew resource management course, which included simulation exercises, at South Shields Marine School (South Tyneside College). *Hebrides*'s master, chief engineer and second engineer had attended the course. The chief officer had attended a similar course with a previous employer and the third officer had completed human element training during his cadetship.

Between about 2010 and 2013, CFL had also arranged a series of 1-day courses on human performance, which were attended by 419 of its employees, 398 of whom were seafarers. The company had also previously employed two human performance auditors.

1.12 LOCHMADDY

Lochmaddy is situated at the north-east corner of North Uist at the head of Loch Maddy. The entrance is bounded by Weavers Point on the Isle of Flodday on the north side and Leac nam Madadh on the south side.

A linkspan ro-ro berth is situated on the south side of the pier. A marina that can accommodate up to 26 small craft on pontoons lies to the south of the linkspan. The water depth alongside the ro-ro berth is between 4 and 7 metres. The height of tide at the time of the accident was 2.4 metres and the wind at the ro-ro berth was south-south-west, Beaufort force 6.

1.13 SIMILAR ACCIDENTS AND INCIDENTS

1.13.1 CFL Ferries Ltd

Isle of Arran (MAIB report 13/2010) – in February 2010, the ro-ro passenger ferry *Isle of Arran* made heavy contact with a linkspan in Kennacraig, West Loch Tarbert, due to the loss of control of the starboard CPP that resulted in the propeller remaining at full ahead pitch. Although full astern pitch was applied to the port CPP, the starboard anchor let go and the starboard engine shut down, these actions did not prevent *Isle of Arran* from landing heavily. The MAIB investigation identified that the factors contributing to the accident were:

- the fitting of an incorrect component
- the lack of technical information leading to incorrect adjustment
- inadequate testing of the pitch control system the lack of a robust technical investigation following a previous failure
- the pitch control system was not tested before the ferry was committed to its entry.

The investigation report stated:

> *'the high speed of approach to the berth and the inability of the ship's crew to quickly identify the cause of the loss of pitch control, made the resultant heavy contact with the linkspan inevitable.'*

Hebridean Isles – in 2010, pitch control was lost on one of the propellers of the ro-ro passenger ferry *Hebridean Isles* when berthing. A heavy landing resulted but damage was minimised by the bridge team using the emergency pitch control system to slow the vessel.

In July 2016, *Hebridean Isles* made heavy contact with the quay, which caused significant damage to its bow visor. During the approach to the berth, the ferry suddenly sheered and the master's attempts to control the sheer using both shafts and bow thruster were unsuccessful. An investigation by CFL did not find any apparent technical fault. The investigation report concluded that the vessel's relatively high approach speed had reduced the time available in which effective corrective action could be taken.

Isle of Mull – in November 2016, the ro-ro passenger ferry *Isle of Mull* was approaching its berth when an alarm sounded indicating a CPP pitch deviation. As the master had attempted to reduce the pitch on both CPPs, pitch control of one of the propellers was lost with ahead pitch set. The master followed a pre-planned response to regain control and was then able to manoeuvre the vessel clear of danger. CFL identified that the successful management of the incident resulted from lessons learned from *Hebrides*' loss of control 2 months earlier.

1.13.2 Other recent accidents resulting from loss of control

Dover Seaways (MAIB report 24/2015) – in November 2014, the ro-ro passenger ferry *Dover Seaways* unexpectedly turned to starboard when leaving Dover. The bridge team attempted to regain control by engaging 'hand' steering and putting the engines full astern, but the ferry struck a breakwater at a speed of about 3.5kts.

The MAIB investigation identified that *Dover Seaways*'s bridge team were not fully familiar with some aspects of the steering control system and did not monitor the rudder angle indicators.

Key Bora (MAIB report 31/2014) – in December 2013, the chemical tanker *Key Bora* was being manoeuvred to its designated berth. As the vessel approached the quay, the pilot ordered astern pitch on the propeller. The CPP did not respond in time and the vessel's bow struck the quay. The MAIB investigation report identified that the tanker's master was unaware of the function of the CPP back-up control system, which could have been used to bring the situation under control.

Sirena Seaways (MAIB report 6/2014) – in June 2013, the ro-ro passenger ferry *Sirena Seaways* made heavy contact with a linkspan after control of the CPP system was lost. The impact caused a hole in the vessel's bow beneath the waterline, which resulted in some flooding and considerable damage to the berth linkspan and mooring towers. During the vessel's approach to the berth, the starboard CPP back-up control system was inadvertently operated. This was not noticed by the bridge team, who did not monitor the pitch indicators. As the vessel approached its berth the CPPs were set astern but failed to respond. The CPP back-up control system was not used. The back-up system was rarely used and its operation was not fully understood.

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 CONTROL FAILURE MECHANISM

It is evident from the inspection carried out by *Hebrides*'s engineers shortly after the accident, that control of the ferry's port CPP was lost due to a mechanical failure within the linear servomotor actuator sited on the port gearbox **(Figure 6)**. The setscrew used to secure one half of the jaw coupling to the stepper motor 'D' shaped shaft had backed off from the shaft's flat surface **(Figures 12** and **14)**. Consequently, although the stepper motor shaft rotated inside the jaw coupling in response to the electrical signals from the remote propulsion consoles, the coupling remained stationary and the shaft's rotary motion was not transferred to the ball screw mechanism. Therefore, the pitch set on the port CPP was unaltered.

The setscrew securing the jaw coupling to the stepper motor shaft had loosened since its installation in March 2016, and the markings on the stepper motor shaft **(Figure 14)** show that the shaft had moved within the coupling prior to its complete disconnection. That the pitch on the port CPP did not reduce below 50% ahead during *Hebrides'*s approach to Lochmaddy indicates that the screw's complete disconnection from the stepper motor shaft occurred at about 1029, immediately after *Hebrides*'s master reduced the pitch on both propellers from 60% to just over 40% ahead. The loosening of the setscrew was due to its lack of rundown torque, the absence of thread locking fluid and vibration during the actuator's operation. The vibration acting on the setscrew was potentially greater than usual due to the bore of the half coupling being locally drilled out to fit it onto the stepper motor shaft instead of being machined to the required tolerance.

2.3 AVAILABILITY OF SERVICE INSTRUCTIONS

The unavailability of Scana's job description for the actuator's inspection **(Annex C)** was pivotal to the failure of the actuator. The instructions were not incorporated into the HeliconX control system manuals provided by RR Marine that were carried on board the ferry. Therefore, the ferry's engineers were not aware of the requirement for an annual inspection or the suggested 15000 hours' lifespan of the equipment. In the absence of annual inspection, it is not surprising that the elastomer spider inside the ferry's original coupling disintegrated in July 2015. Its 55000 hours in service over 15 years exceeded the manufacturer's suggested lifespan by a factor of over 3.5.

The RR Marine service engineer who replaced part of the jaw coupling in March 2016 was also unaware of Scana's actuator inspection instructions and had to rely on his knowledge gained from working on other Helicon systems. However, as the actuators were generally reliable, and the service engineer had no experience in taking them apart or replacing components, the replacement of this critical part was based on his general engineering knowledge rather than by the adherence to specific requirements. Among other things, this resulted in the setscrew being tightened without the application of thread locking compound to bond the threaded surfaces together, which contributed significantly to the setscrew backing off the stepper motor shaft. It also possibly explains why the service engineer did not question the need to increase the diameter of the bore in the coupling so that it would fit onto the stepper motor shaft, an action that probably increased the clearance between the shaft and the coupling beyond the intended 0.03mm.

Although the coupling was inspected by the ferry's engineers in July 2016, the engineers were focused on the condition of the 'spider' and the setscrew probably had not backed off sufficiently by then to be apparent. The engineers would also not have known to check that the setscrew had been secured with thread locking compound.

2.4 SETSCREW

The RR technical analysis of the actuator **(Annex A)** and **Figures 12**, **13** and **14** show that the 'cone' point of the setscrew had deformed under load and that the point had not penetrated the flat surface of the stepper motor shaft. However, the use of a 'cone' point setscrew in this type of application was not unusual, and the degree to which these factors contributed to the failure was marginal. 'Cone' point setscrews are generally suited to permanent fittings whereas 'cup' pointed setscrews are suited for use in conjunction with metals of differing hardness. Both types of setscrew were likely to have loosened and backed off if not used in conjunction with thread locking compound.

2.5 ENGINEERING BARRIERS

The fitting of a pitch deviation alarm and/or an automatic clutch-out capability in the HeliconX control system, as recommended by RR Marine in 2013 **(Annex B)**, was intended to immediately alert bridge teams to a difference between pitch demanded and pitch achieved and to reduce the possibility of an accident ensuing. In this case, the actuator coupling controlling the port CPP failed at about 1029, but the bridge team did not realise that control of the port CPP was lost until about 2 minutes later when the third officer saw that the pitch had not reduced below 50% ahead. During this period, *Hebrides* continued to close Lochmaddy at a speed of between 10 and 13kts and the available options for action reduced considerably.

Due to the absence of procedures within CFL for dealing with information from OEMs, and the company's lack of a record of the RR Marine service letter detailing the recommended upgrades to the HeliconX control system, it has not been possible to determine why the upgrades were not implemented. Although the recommended work would have required CMAL's approval, it would have taken only 1 or 2 days, and the resulting safeguards would have been of significant benefit.

2.6 DETECTION OF LOSS OF PITCH CONTROL

Other than concern about the weather conditions that prompted *Hebrides*'s master to use the central channel towards Lochmaddy, the ferry's approach was routine. By the time it passed the planned abort position to the north of Ruigh Laith light at 1029 the ferry's crew were in their designated positions for standby, the ferry's speed had been reduced and the arrival checklist had been completed. The master had also transferred propulsion control to the starboard wing console and had seen the pitch of both CPPs start to respond following his movement of the pitch control levers from 60% to 40% ahead.

However, over the next 2 minutes the bridge team were unaware that the remote control of the port CPP had been lost with the pitch remaining at 50% ahead. Monitoring of the pitch indicators had stopped as soon as the pitch had started to reduce from 60% ahead, and the discrepancy between the pitch demanded and the pitch achieved was insufficient to result in a discernible difference in the ferry's speed. It was only at 1031, when the master noticed *Hebrides*'s speed was not reducing after he had set the pitch on the port CPP to 70% astern, that he realised there was a potential problem. By then, the ferry was less than 200m from the pier roundhead and was still making good 10kts.

2.7 INITIAL REACTIONS

That *Hebrides*'s master initially considered the ferry's trim was the cause of its faster than expected speed, was probably influenced by his confirmation that propulsion control had been successfully transferred to the starboard wing console. When he eventually realised that bridge control of the port CPP had been lost, the master's actions indicate that he experienced a 'startle effect' to some degree.

The startle effect includes both physical and mental responses to a sudden and unexpected stimulus. Although the physical responses are automatic and virtually instantaneous, the effect disrupts cognitive processing and can negatively influence an individual's decision making and problem solving abilities.

In this case, the master's action to set the starboard CPP to 100% astern was instinctive and immediate. However, it resulted in the ferry turning towards Lochmaddy due to the port CPP driving ahead and the starboard CPP driving astern. Although the master immediately attempted to arrest the swing using the bow thruster, the thruster would have initially had little effect due to the ferry's speed. The master's actions were focused entirely on countering the effects of the pitch of the port CPP remaining at 50% ahead rather than eliminating the problem. The options of switching to the emergency pitch control system then de-clutching the port engine were not instinctive and were overlooked at this stage.

2.8 SUBSEQUENT ACTIONS

From 1031, when *Hebrides* passed close to the south of the pier roundhead, until 1039 when the ferry landed heavily on the pier, the master was never in full control of its movements. He used the thrusters to prevent *Hebrides* from turning into the linkspan but, because the use of the starboard CPP alone was insufficient to stop the ferry, the master was unable to prevent it from running over the marina pontoons and grounding. Subsequent actions then resulted in the ferry re-floating, backing over the pontoons and making heavy contact with the pier. During this brief and hectic period, the efforts of the bridge and the ECR teams to re-establish control of the port CPP were well-intentioned. However, the actions taken were un-coordinated, particularly after the attempts to use emergency pitch control had been unsuccessful due to the failure being mechanical rather than electrical. Among other things:

- The master was unaware that the port CPP was put into local control and the pitch was set to 0˚.

- The attempt to de-clutch the port engine from the starboard wing console was unsuccessful because control of the port CPP had been transferred to the ECR.

- Prior to the grounding, the port shaft was de-clutched when the port CPP was in local control.

- No adjustments were made to the pitch set on the starboard CPP or the bow thrusters when the ferry grounded.

- After backing over the pontoons, the port shaft was clutched-in again despite the cause of the loss of control not being identified and rectified.

It is highly likely that stress and panic were significant factors that reduced the master's situational awareness regarding the status of the control of the port CPP. However, poor communication between the bridge, the ECR and the engine room was also a factor. It was only when *Hebrides* was in the open water to the east of Lochmaddy that the master and the bridge and ECR teams had time to take stock of the situation, assess the damage, and consider the passengers' safety and the options for berthing.

2.9 APPROACH SPEED

The stress and panic experienced by the master was probably exacerbated by the pressure of *Hebrides*'s approaching Lochmaddy at a speed of over 10kts when the loss of control of the port CPP became apparent. As the ferry was only 200m from the roundhead, the relatively fast speed of the approach impacted on the time he had available to react.

A review of a number of *Hebrides*'s previous entries into Lochmaddy showed that the ferry's approach speed was not faster than normal. However, although the speed reflected the manoeuvrability of the ferry and the master's familiarity with its handling characteristics and the intended berth, it left little room for error or mechanical failure. On this occasion, it was evident from the contact with the mooring pontoons within 2 minutes of the master using full astern power on the starboard shaft, that the speed of the approach was too fast for such action to be effective.

2.10 EMERGENCY PREPAREDNESS

The circumstances of this case, and those of the small sample of recent similar accidents and incidents detailed in paragraph 1.13, show that an effective response to the loss of propulsion or directional control is essential, particularly when operating close to navigational dangers. CFL had developed procedures and practices to help ensure the safe navigation of its ferries, such as the arrival checklist, the formalisation of abort points and the establishment of the 'Red Zone' on the bridge during standby. However, the operator did not apply similar focus on equipping its crews to deal with situations when things went wrong.

Hebrides's bridge and ECR teams were not sufficiently prepared or practised to deal quickly and effectively with the loss of pitch control in the confined waters off Lochmaddy. That they had not conducted loss of propulsion control drills and a contingency plan for the use of 'local' control of the CPPs had not been developed as prompted by risk assessment, were contributory in this respect. It is likely that these measures would have made initial actions to regain control more instinctive, helped to identify the communication problems between the bridge and the engine room and given the master more confidence in the use of reversionary methods of pitch control. Although the card covering ‘critical equipment failure’ in *Hebrides*’s ‘Master’s Decision Support System’ **(Annex D)** provided general guidance, it was of little use with respect to the immediate actions required.

SECTION 3 - CONCLUSIONS

3.1 SAFETY ISSUES DIRECTLY CONTRIBUTING TO THE ACCIDENT THAT HAVE BEEN ADDRESSED OR RESULTED IN RECOMMENDATIONS

1. Control of *Hebrides*'s port CPP was lost due to a mechanical failure within a linear servomotor actuator sited on the port gearbox. [2.2]

2. The mechanical failure was caused by the loosening of a setscrew used to attach a coupling to a stepper motor shaft due to its lack of rundown torque, the absence of thread locking fluid, and vibration during the actuator's operation. [2.2]

3. The absence of service instructions for the actuator's inspection and maintenance that were available from its manufacturer was pivotal to the failure. [2.3]

4. No thread locking compound was applied to the setscrew when part of the actuator's coupling was replaced in March 2016. [2.3]

5. The pitch control system had not been upgraded to incorporate a pitch deviation alarm and/or an automatic clutch-out capability as recommended by its manufacturer. [2.5]

6. It has not been possible to determine why the upgrades to the pitch control system were not implemented by CFL due to the operator not having procedures to deal with information received from manufacturers of its shipborne equipment. [2.5]

7. It took the bridge team 2 minutes to realise that control of the port CPP had been lost. By then, the ferry was less than 200m from the pier roundhead and was still making good 10kts. [2.6]

8. When the master realised bridge control of the port CPP had been lost, his actions indicate that he experienced a 'startle effect' to some degree and the options of switching to the emergency pitch control system and/or de-clutching of the port engine were not instinctive and were initially overlooked. [2.7]

9. The efforts of the bridge and the ECR teams to re-establish control of the port CPP were well-intentioned but they were un-coordinated. [2.8]

10. It is highly likely that stress, panic and poor communication contributed to the master's situational awareness regarding the status of the control of the port CPP. [2.8]

11. *Hebrides*'s speed when approaching Lochmaddy was too fast to enable the actions taken by the master to stop the ferry in safe water to be effective. [2.9]

12. *Hebrides*'s bridge and ECR teams were not sufficiently prepared or practised to deal quickly and effectively with the loss of pitch control in the confined waters off Lochmaddy. [2.10]

SECTION 4 - ACTION TAKEN

4.1 ACTIONS TAKEN BY OTHER ORGANISATIONS

Rolls-Royce Marine has:

- Issued a service letter to all users of the HeliconX propulsion control systems regarding the inspection and integrity of the jaw coupling within the linear servomotor actuator.

- Issued a service procedure for the linear servomotor based on OEM requirements.

CalMac Ferries Ltd has:

- Issued a technical bulletin to its major vessels that requires all propulsion controls, including emergency controls, at all stations are tested regularly.

- Conducted its own investigation of the accident. The investigation report made recommendations related to, among other things:

    - The conduct of a failure mode analysis on the pitch control systems to identify potential for single point failure of normal and secondary emergency pitch control arrangements.

    - The establishment of a working group of masters to assess the approach speeds at all berths included in the company issued passage plans and to provide guidance as appropriate.

    - Measures to improve operational familiarity with propulsion emergency control systems and the application of HELM techniques in routine and emergency operations.

    - Improving the 'Master's Decision Support System' and associated management system components.

- Fitted pitch deviation alarms on board *Hebrides* and its other vessels using the HeliconX control system.

- Fitted a fixed communication system on board *Hebrides* between the CPP control position on the gearbox and the bridge.

SECTION 5 - RECOMMENDATIONS

Rolls-Royce Marine is recommended to:

2017/136 Verify its processes to ensure that service and inspection instructions provided by the original equipment manufacturers of the components used in its control systems are available to its service engineers and in the documentation provided to vessels.

CalMac Ferries Ltd is recommended to:

2017/137 Implement procedures that:

- Document and process recommendations for safety critical system upgrades received from manufacturers.
- Introduce drills and contingency plans to better prepare its crews to deal with propulsion failures.

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

Marine Accident Report