ACCIDENT REPORT

Combined report on the investigations of the sinking and abandonment of the DUKW amphibious passenger vehicle

Wacker Quacker 1

in Salthouse Dock, Liverpool

on 15 June 2013

and the

fire and abandonment of the DUKW amphibious passenger vehicle

Cleopatra

on the River Thames, London

on 29 September 2013

MAIB
MARINE ACCIDENT INVESTIGATION BRANCH

VERY SERIOUS MARINE CASUALTY REPORT NO 32/2014 DECEMBER 2014

Extract from

The United Kingdom Merchant Shipping

(Accident Reporting and Investigation)

Regulations 2012 – Regulation 5:

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NOTE

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

A	-	Ampere
AIS	-	Automatic Identification System
APV	-	Amphibious passenger vehicle
BCTQ	-	Burness Corlett Three Quays Ltd
BV	-	Bureau Veritas
°C	-	Degrees Celsius
CCTV	-	Closed-circuit television
COIF	-	Certificate of initial fitness for road use
DfT	-	Department for Transport
DPA	-	Designated Person Ashore
DSC	-	Digital selective calling
DSM Code	-	Domestic Passenger Ship (Safety Management Code) Regulations 2001
GPS	-	Global positioning system
kg	-	kilogram
kPa	-	kilopascal
kt	-	knot
kW	-	kilowatt
LDT	-	London Duck Tours Ltd
LFB	-	London Fire Brigade
LSA	-	Life saving appliance
m	-	metre
m^3	-	cubic metres
MCA	-	Maritime and Coastguard Agency
MGN	-	Marine Guidance Note
mm	-	millimetre

mph	-	miles per hour
MSN	-	Merchant Shipping Notice
MTB	-	Marine transfer box
MTL	-	Materials Technology Ltd
N	-	Newton
NTSB	-	National Transportation Safety Board
NVIC	-	Navigation and Vessel Inspection Circular
PFD	-	Personal flotation device
PLA	-	Port of London Authority
PSV	-	Public Service Vehicle
RIB	-	Rigid-hulled inflatable boat
RNLI	-	Royal National Lifeboat Institution
rpm	-	Revolutions per minute
t	-	tonne
TYD	-	The Yellow Duckmarine
UJ	-	Universal joint
V	-	volts
VHF	-	Very High Frequency
VOSA	-	Vehicle and Operator Services Agency
VTS	-	Vessel Traffic Services
WQ	-	Wacker Quacker
WW2	-	World War 2

TIMES: All times in this report are UTC unless otherwise stated

SYNOPSIS

At about 1553 on 15 June 2013, the amphibious passenger vehicle *Wacker Quacker 1* sank by the bow during a sightseeing tour in Salthouse Dock, Liverpool. The vehicle's 31 passengers and 2 crew abandoned into the water and either swam ashore or were recovered without serious injury by the crews of three recreational narrowboats. *Wacker Quacker 1* had suffered severe flooding through two holes that had been torn in its hull when its propeller was fouled by a discarded car tyre.

At about 1150 on 29 September 2013, a fire broke out on board the amphibious passenger vehicle *Cleopatra* during a sightseeing tour on the River Thames, London. Its 28 passengers and 2 crew were also forced to abandon the vehicle and were recovered from the water without serious injury by the crews and passengers of three commercially operated rigid-hulled inflatable boats.

Wacker Quacker 1 was the second amphibious vehicle to sink in Salthouse Dock within a 3-month period; on both occasions the vehicles did not have the quantity of buoyancy foam required to provide the mandated level of residual buoyancy. Following the sinking of *Wacker Quacker 1*, the Maritime and Coastguard Agency discovered that the London-based amphibious passenger vehicles were being operated with about two thirds of the buoyancy foam required to meet the UK's damaged survivability standard. As a result, the vehicles were temporarily taken off the water to allow the operator to fit the additional foam needed to ensure its vehicles remained afloat in the fully flooded condition. In order to achieve this, additional unsecured and unprotected buoyancy foam was tightly packed around the engine compartment and in the void spaces under the passenger deck. This increased the ambient temperatures in and around the vehicles' engine compartments.

The investigation concluded that:

- Prior to the sinking of *Wacker Quacker 1*, the Liverpool and London operators (The Yellow Duck Marine and London Duck Tours, respectively) had failed to meet the UK's mandated buoyancy standard; when the London Duck Tours did, it introduced the circumstances that led to the fire on board *Cleopatra*.

- The Liverpool based vehicles had been poorly maintained and their material condition had been allowed to progressively deteriorate to an unsafe level over a prolonged period of time.

- In both instances, the crew had little time to co-ordinate the evacuation process and the confined nature of passenger spaces made it almost impossible for them to control or assist the passengers.

Factors contributing to the accidents included:

- In respect to buoyancy, the operators had not taken appropriate action to address the lessons learned from previous high profile accidents and from recent similar hazardous incidents.

- In Liverpool, the passengers and crew were not adequately prepared to deal with the emergency situation.

- The Maritime and Coastguard Agency's periodic survey and inspection regimes, and their unscheduled interventions had been ineffective.
- The Maritime and Coastguard Agency surveyors with responsibility for amphibious passenger vehicles had not been provided with appropriate instructions, guidance or training.

The investigation also identified that the Department for Transport's Maritime and Coastguard Agency and Vehicle and Operator Services Agency both had long-standing concerns over the safe operation of these vintage amphibious vehicles. But they did not share their concerns or knowledge effectively before or following the sinking of the two Liverpool vehicles. The fire on board *Cleopatra* could easily have occurred on the road and therefore come under the jurisdiction of the land based regulator.

In response to MAIB recommendation SB3/2013, the Maritime and Coastguard Agency took action to temporarily suspend amphibious operations on the River Thames. It has also provided guidance to its surveyors to help them verify the volume of foam fitted into the hulls of amphibious vehicles, and has carried out an internal investigation into the performance of its Liverpool and Orpington Marine Offices. London Duck Tours has modified its vehicles to provide an alternative method of satisfying the damaged survivability standard, and has subsequently been permitted to resume its waterborne operations. The Yellow Duckmarine has been put into administration and the north-west Traffic Commissioner has withdrawn its Passenger Service Vehicle licence.

Recommendations have been made to the Maritime and Coastguard Agency and the Driver and Vehicle Standards Agency with the aim of improving cross agency information flow, the standard of APV surveys and inspections and improving the industry's operational practices. London Duck Tours Ltd has been recommended to carry out a thorough assessment of the risks introduced by any future modifications to its vehicles.

SECTION 1 - FACTUAL INFORMATION *WACKER QUACKER 1*

1.1 PARTICULARS OF *WACKER QUACKER 1* AND ACCIDENT

SHIP PARTICULARS	
Vessel's name	*Wacker Quacker 1*
Flag	UK
Certifying authority	Maritime and Coastguard Agency
Vessel type	Class V passenger vessel
Vehicle chassis number	353-19572
Vehicle type	DUKW amphibious passenger vehicle
Year of build	1945 (converted to APV in 2001)
Registered owner	Pearlwild Ltd
Trading name	The Yellow Duckmarine
Construction	Steel
Hull length	9.45m
Length overall	10.43m
Width overall	2.55m
Height of canopy (from the road)	4.1m
On road weight	8.3t
VOYAGE PARTICULARS	
Port of departure	Salthouse Dock, Liverpool, England
Port of arrival	Salthouse Dock, Liverpool, England
Type of voyage	Sightseeing tour, inland waterways
Manning	2
MARINE CASUALTY INFORMATION	
Date and time	15 June 2013 at about 1553
Type of marine casualty or incident	Very Serious Marine Casualty
Location of incident	Salthouse Dock, Liverpool
Place on board	Propeller shaft tunnel
Injuries/fatalities	Nil
Damage/environmental impact	Nil
Ship operation	Sightseeing tours
Voyage segment	Arrival
External & internal environment	Daylight, dry and clear, sheltered waters.
Persons on board	33 (2 crew + 31 passengers)

1.2 BACKGROUND

Amphibious passenger vehicles (APV) are widely used throughout the world by tourism and leisure companies to deliver land and waterborne sightseeing tours. The modern amphibious sightseeing tour concept originated in the USA when, in 1946, an American businessman bought a surplus US army DUKW[1] amphibious vehicle and modified it to carry passengers **(Figure 1)**. Over the following 60 years, the amphibious sightseeing tour concept evolved, with fleets of converted DUKWs, other ex-military vehicles and a variety of specifically designed commercial APVs operating in many major cities across the world.

In 2000, the American business model was replicated in the UK when the first APV sightseeing tours were introduced on the River Thames, London, by the London Frog Company Ltd. A year later, a similar operation was started in Liverpool. By 2013, four converted DUKWs, *Wacker Quacker 1* (*WQ1*), *Wacker Quacker 2* (*WQ2*), *Wacker Quacker 4* (*WQ4*) and *Wacker Quacker 8* (*WQ8*), were being operated in Liverpool's South Docks[2] complex by Pearlwild Ltd under the trading name of The Yellow Duckmarine (TYD).

On 30 March 2013, *WQ4* sank **(Figure 2)** while under tow in Salthouse Dock, Liverpool. There was no one on board at the time, and the sinking was investigated by the Maritime and Coastguard Agency (MCA). During its investigation, the MCA discovered that the hulls of TYD's vehicles did not contain the appropriate quantities of buoyancy foam required to keep them afloat when flooded. The MCA immediately suspended TYD's waterborne operations and instructed the company to insert an agreed volume of additional foam. TYD engaged the services of an independent firm of naval architects, Burness Corlett Three Quays Ltd (BCTQ), to calculate how much foam was needed to meet the MCA's requirements. Six weeks later, having satisfied the MCA that it had met its buoyancy standards, TYD resumed its operations on the water.

1.3 NARRATIVE

At about 0900 on 15 June 2013, the master of the DUKW *WQ1* **(Figure 3)**, and his driver, arrived for work at TYD's fleet maintenance garage in Liverpool, England. The company's mechanics, having carried out their daily maintenance routines the night before, presented *WQ1* for inspection. The master and driver examined *WQ1* and completed the vehicle *drivers'/masters'* safety checklist **(Annex A)**. They then drove *WQ1* from the garage to TYD's passenger pick-up point on Gower Road, adjacent to Salthouse Dock **(Figure 4)**.

WQ1 was one of three TYD vehicles operating that day and was scheduled to undertake seven tours between 1000 and 1830. At 0950, the master started to board the passengers for his first tour. Ten minutes later, *WQ1* departed with 30 passengers on board. The road trip around the city centre and the waterborne tour through the interlinked southern docks complex took about 55 minutes to complete. During each trip, the master sat next to the driver and assumed the role of the tour guide **(Figure 5)**.

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[1] A DUKW (Pronounced "duck") is an amphibious landing vehicle that was designed to transport military personnel and supplies for the US army during World War 2. The acronym DUKW indicates that the vehicle was designed in 1942 (D), it is an amphibian (U) and has both front-wheel and rear-wheel drive capability (K and W respectively).

[2] Liverpool's South Docks complex is made up of six interlinked docks (Salthouse Dock, Albert Dock, Wapping Dock, Queens Dock, Coburg Dock and Brunswick Dock) that have significant heritage value and have been redeveloped specifically for the tourism trade.

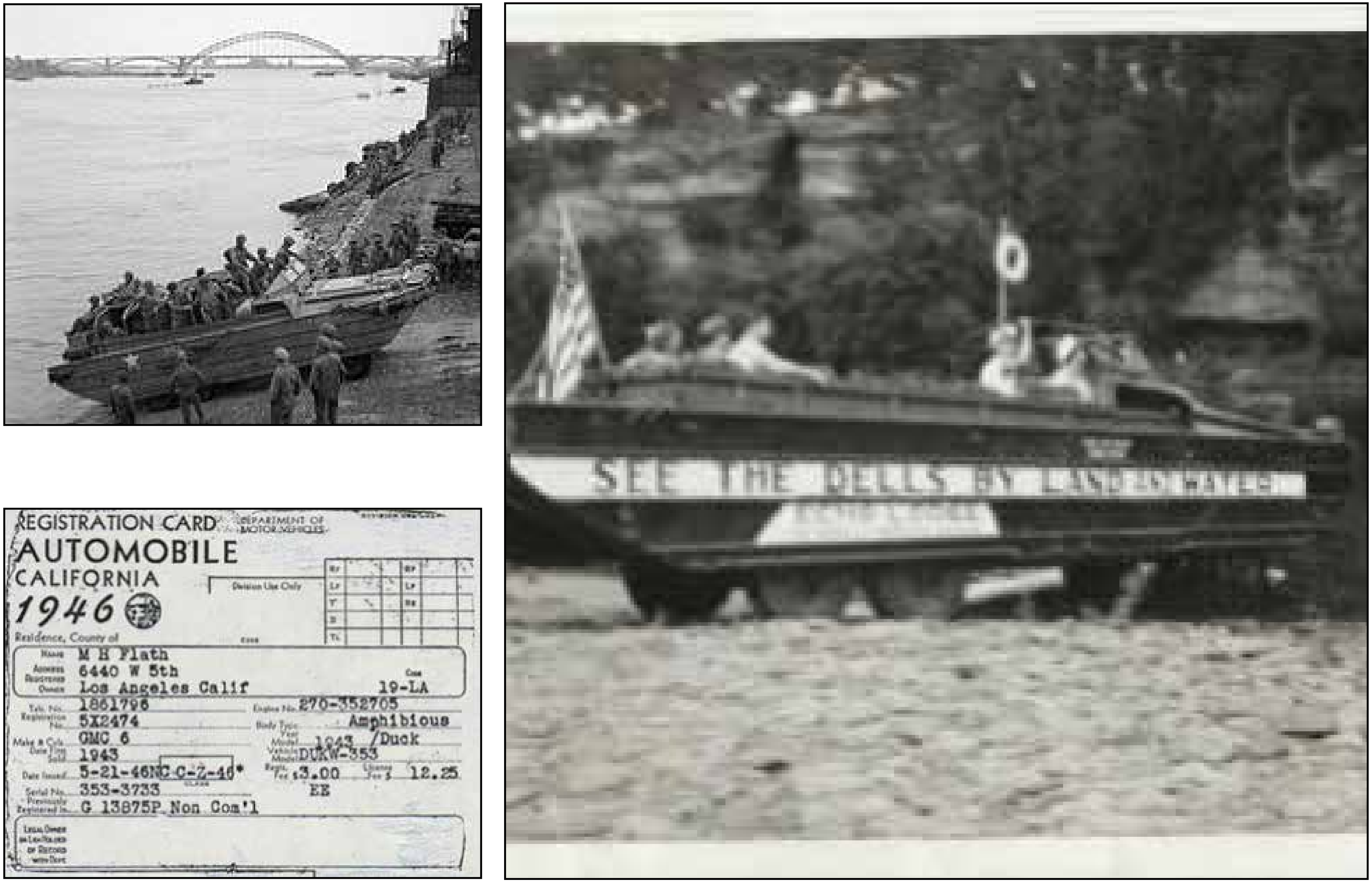


Figure 1: First DUKW amphibious vehicles used to carry passengers in the Wisconsin Dells, USA

Images courtesy of Roger O Doherty

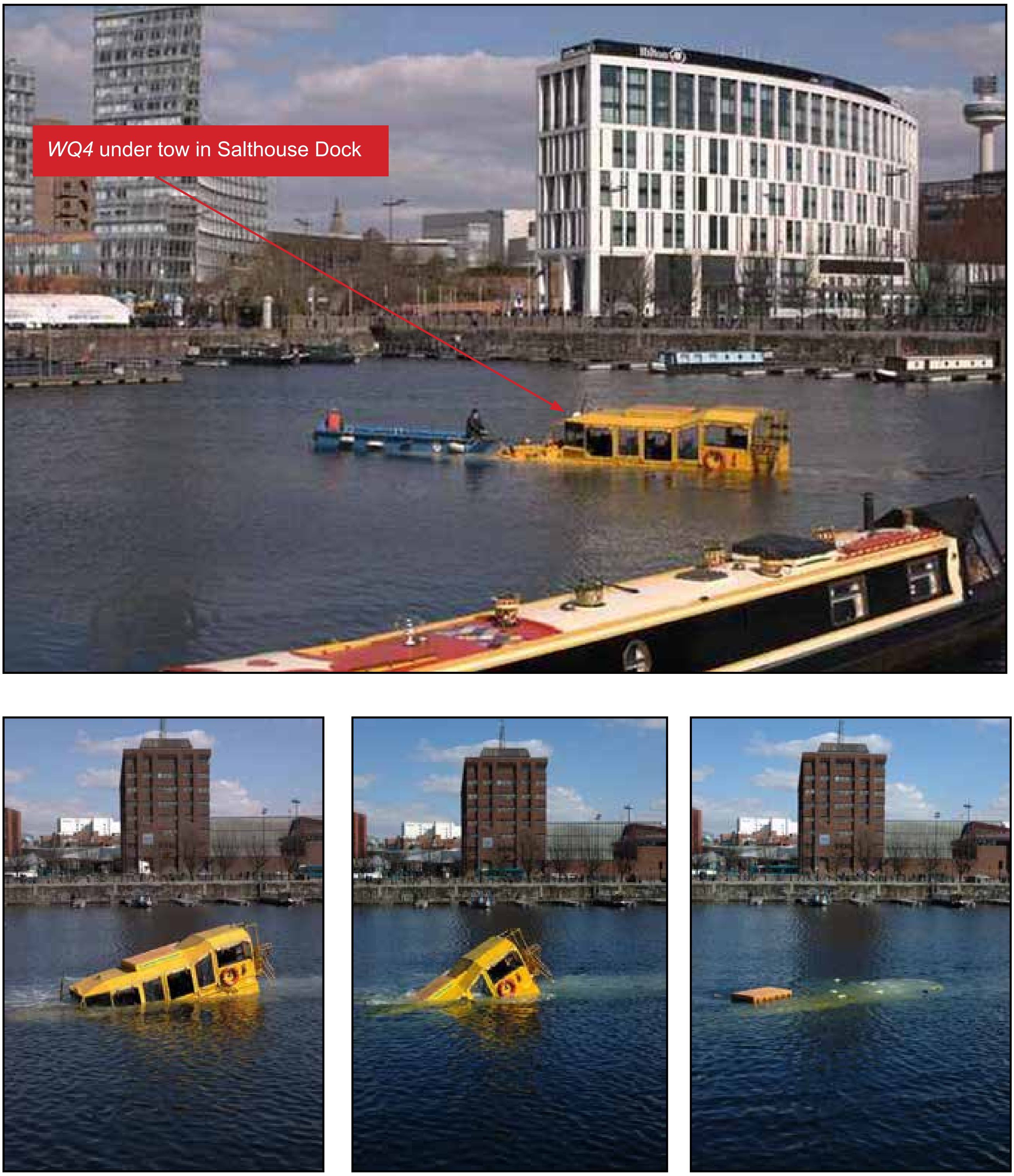


Figure 2: *Wacker Quacker 4* sinking in Salthouse Dock, Liverpool, on 30 March 2013

Figure 3: Amphibious passenger vehicle *Wacker Quacker 1*

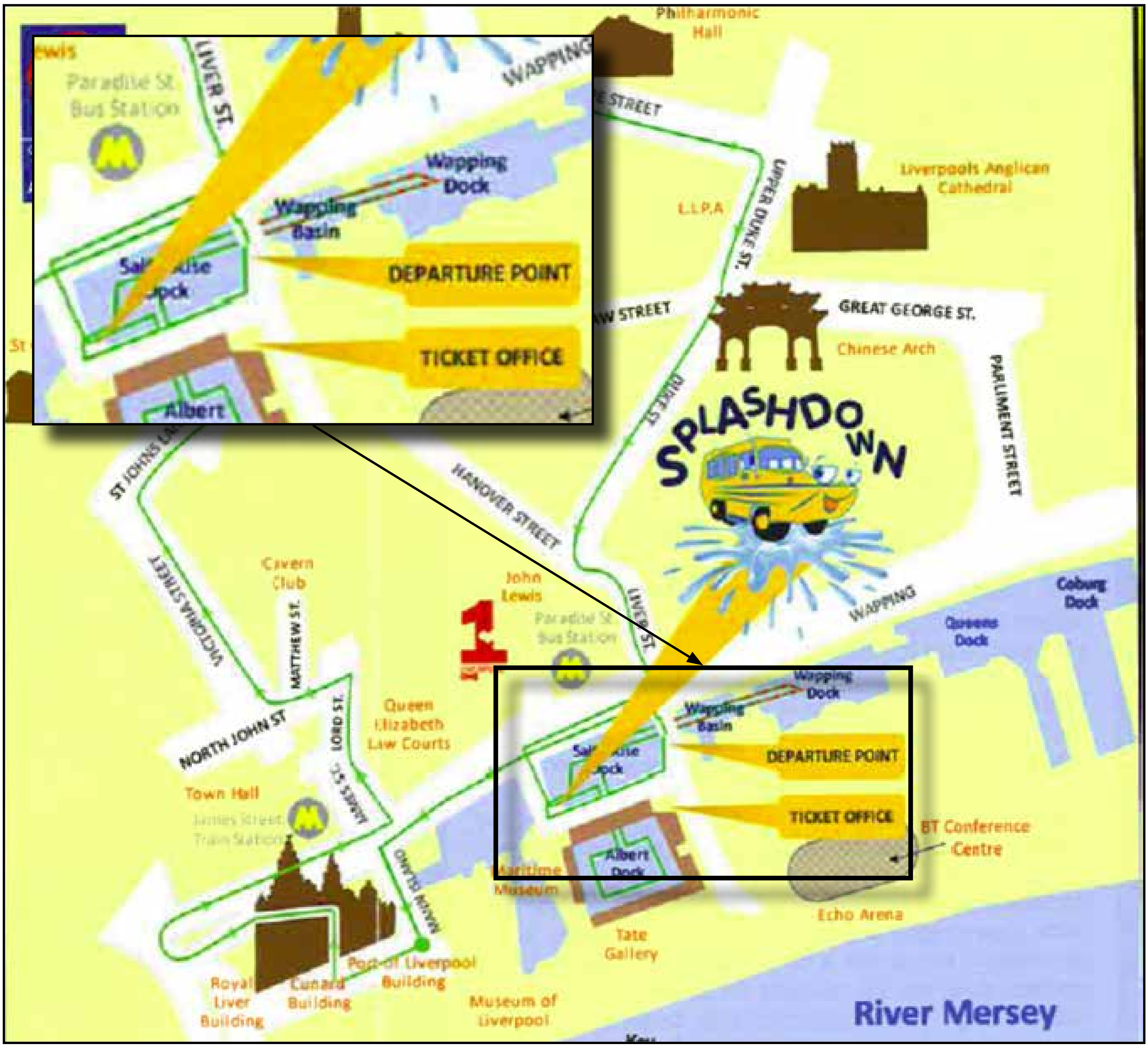


Figure 4: The Yellow Duckmarine amphibious passenger vehicle sightseeing tour route

Figure 5: Crew positions during sightseeing tour

At about 1204, having completed the waterborne section of the third tour of the day, the driver attempted to drive *WQ1* up the Salthouse Dock slipway. During his approach, the driver increased the vehicle's propeller speed and attempted to engage six-wheel drive. When *WQ1*'s wheels made contact with the slipway the vehicle began to climb out of the water. The driver almost immediately realised that the engine was losing power **(Figure 6)**. Concerned that the engine might stall, the driver aborted his attempt to exit the dock and allowed *WQ1* to roll back into the water. He put the propeller astern and manoeuvred backwards to make room for a second attempt. The second attempt was successful and the passengers were driven to Gower Street, where they were disembarked.

At 1454, *WQ1* set off on its fifth tour of the day with 31 passengers on board. Four of the passengers were children, the youngest of whom, a 2 year old girl, was sitting on her mother's lap at the back of the vehicle **(Figure 7)**. At 1529, *WQ1* arrived at the South Docks complex and stopped on the road opposite the Salthouse Dock access slipway. Fifteen seconds later, the driver manoeuvred *WQ1* to the top of the slipway, sounded the vehicle's horn and then drove it into the water **(Figure 8)**.

The driver followed the company's normal route through the interlinked Salthouse, Wapping and Albert docks **(Figure 4)**. At 1546, the driver manoeuvred *WQ1* out of Albert Dock and began his approach towards the Salthouse Dock slipway. At 1548, *WQ1*'s wheels made contact with the slipway and the vehicle began to climb out of the water. Again, the driver lost power and had to abort his attempt to exit the water and allowed *WQ1* to roll back into the dock.

As the driver attempted to manoeuvre *WQ1* into position to make a second attempt to climb the slipway, a thud was heard towards the back of the vehicle and its drive shafts started to vibrate. The driver alerted the master to the problem and they decided to make their way to Coburg Dock, which had a slipway with a less steep incline.

1204:37 *WQ1* approaches slipway

WQ1 frontwheels land on slipway

WQ1 loses power on slipway, driver aborts attempt to exit dock.

1205:29 *WQ1* rolls down slipway and manoeuvres astern

WQ1 2nd approach to slipway

1206:41 *WQ1* climbs out of Salthouse Dock

Figure 6: *Wacker Quacker 1*'s failed attempt to exit Salthouse Dock at 1205 on 15 June 2013

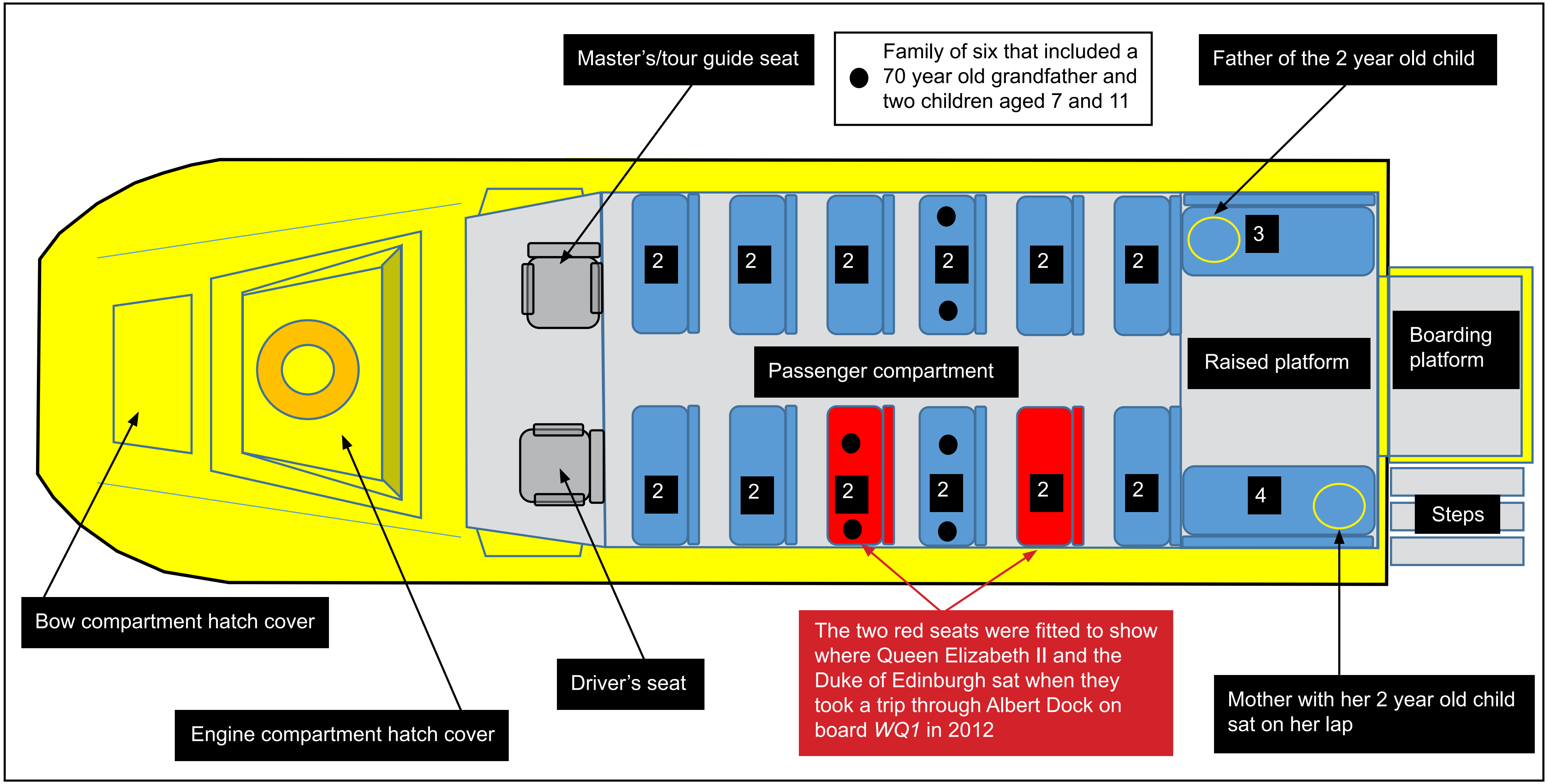


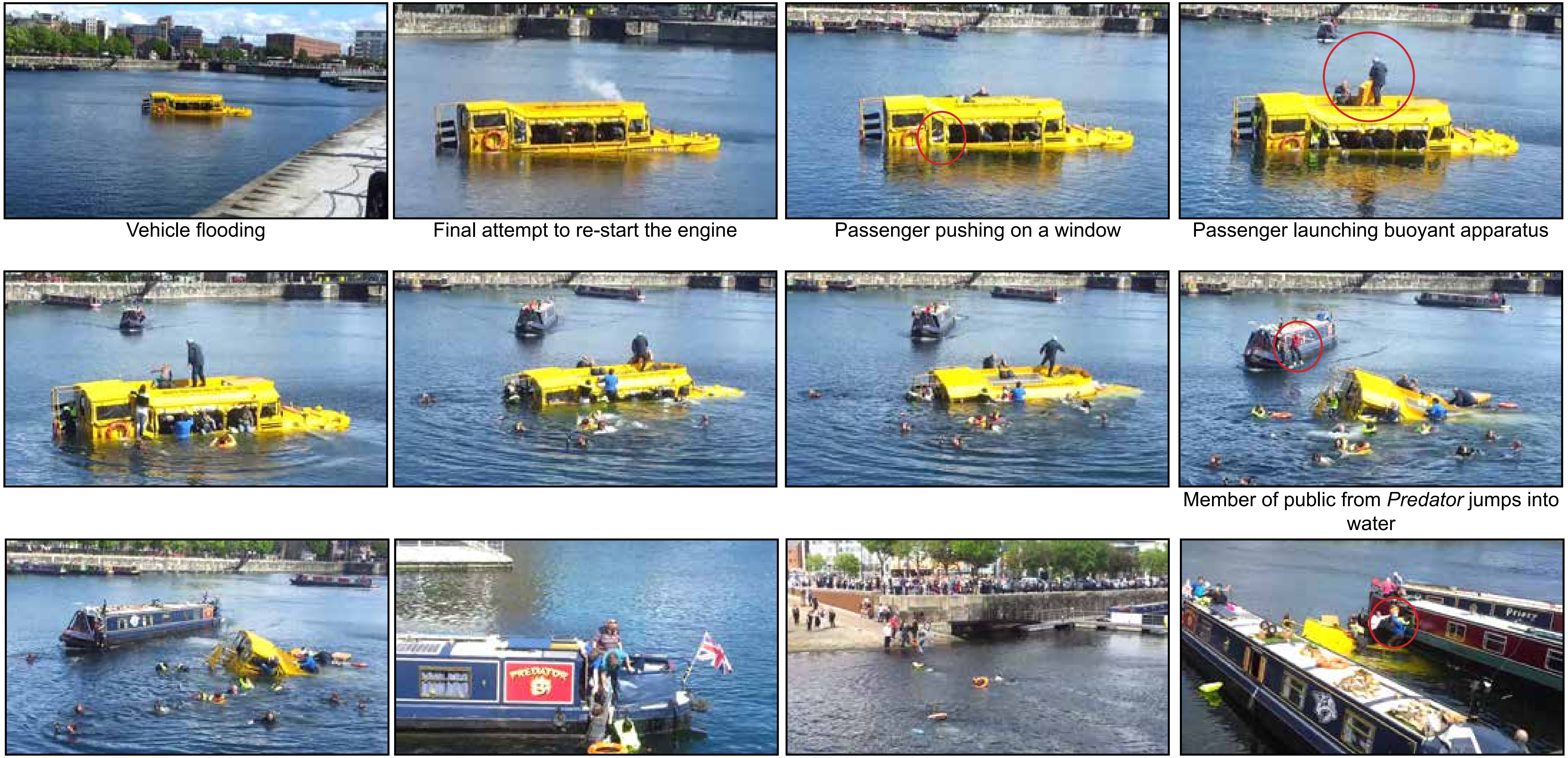
Figure 7: *Wacker Quacker 1's* passenger and crew seating arrangements

Figure 8: Splashdown into Salthouse Dock

As *WQ1* drifted astern, the driver was unable to disengage the water propeller drive shaft, and the engine stalled. The master tried to help the driver by kicking the gear levers. At the same time, passengers at the back of the vehicle saw water flooding in from under their seats and began to shout to the crewmen at the front. Initially, the master continued to help the driver who was asking him where the company mobile phone was. With the water level rising rapidly the passengers began to scream and shout even more. The passengers on the upper level at the back of the vehicle grabbed lifejackets from a box under one of the aft bench seats and began to pass them forward. The master went to the back of the vehicle to help distribute the lifejackets and give instructions to the passengers.

Within 1 minute, the water level within the passenger space had reached the top of the forward facing seats and some of the passengers began to panic. Members of the public on the dockside and the owners of several recreational narrowboats, which were berthed in the dock, began to realise that there was a serious problem on board *WQ1*. As the tourists began to gather at the water's edge, several narrowboats left their moorings and went to help.

The master tried to calm his passengers and told them to put their lifejackets on and remain at their seats. Most of the passengers could not see or hear the master and started to evacuate through the windows **(Figure 9)**. With water now beginning to lap over the vehicle's side coaming into the passenger space, more and more passengers leapt into the water. A 70 year old male passenger, who had climbed out of his window and onto the roof, began to launch the vehicle's buoyant floats.



Vehicle flooding

Final attempt to re-start the engine

Passenger pushing on a window

Passenger launching buoyant apparatus

Member of public from *Predator* jumps into water

Passenger recovered on board *Predator*

Passengers swimming ashore

2 year old child placed onto narrowboat

Figure 9: Abandon ship and rescue sequence

At 1553, after about 2 minutes' flooding, the bow of *WQ1* sank. As it did so the master jumped off the boarding platform at the back of the vehicle and into the water and the driver, who was momentarily submerged, had to escape through the forward port side window and swim to the surface. By now, most of the passengers were in the water and most were not wearing lifejackets. As the first of the narrowboats, *Predator 3*, arrived on the scene, one of its occupants leapt from its bow into the water to help rescue the passengers. Members of the public who had gathered on the dockside and on the access slipway, alerted the emergency services and started to throw lifebuoys into the dock.

WQ1's bow had hit the dock bed but its stern remained afloat. The last passenger to leave the vehicle was the mother of the 2 year old child. She had passed her daughter through the port aft window to her husband, before climbing over the stern door onto the aft boarding platform. Most of the passengers were rescued from the water, or transferred from the stern of the vehicle onto the canal narrowboats that came to their assistance. Some of the stronger swimmers swam to the slipway and walked ashore.

TYD's operations manager ran from her office to *WQ8*, which was in the process of boarding passengers, and alerted its master. The operations manager returned to her office and *WQ8* was driven away from Gower Road. By now, paramedics, police officers, ambulances and fire engines were on scene, and a search and rescue helicopter was in the air. At 1556, TYD's operations manager ran from her office to the scene.

Initially there was some confusion over the number of persons that had been on board, and when a headcount was carried out nine passengers were unaccounted for. Some of the missing passengers had already been taken to hospital for assessment and the others had returned to their hotels to change their clothes. Confirmation that all passengers and crew had been rescued and were safe was achieved at 1745.

Later in the evening, police divers carried out an underwater inspection **(Figure 10)** of *WQ1* and then attached recovery slings to the vehicle's rear wheel axle. Once recovered back onto the slipway, *WQ1* was inspected and photographed by a Merseyside Police scene of crime officer. The police discovered a car tyre wrapped around the propeller and found two large holes in the vehicle's propeller shaft tunnel shell plating **(Figure 11)**.

1.4 ENVIRONMENTAL CONDITIONS

It was a dry day, the wind was slight and the waters in the docks were flat calm. The ambient air temperature was about 20ºC and the water temperature was about 15ºC. Liverpool's South Docks was filled with salt water taken from the tidal River Mersey, and the depth of water where *WQ1* sank was approximately 4.5m.

1.5 THE YELLOW DUCKMARINE

1.5.1 Company history and structure

In 2001, Liverpool Duck Tours Ltd launched its amphibious sightseeing tours around the streets of Liverpool city centre and through the city's historic South Docks complex. In 2003, Pearlwild Ltd purchased Liverpool Duck Tours Ltd and started to

Figure 10: Police divers' underwater survey

Figure 11: Photographs taken by police after the recovery of *Wacker Quacker 1*

trade under the name The Yellow Duckmarine. In the months leading up to the accident, the company employed 35 staff and was operating up to 28 tours each day.

The company structure comprised an operations department, which was led by the operations manager, and an engineering department, which was led by the director of engineering. The operations team was located in an office next to the tour company's ticket office in the Albert Dock buildings **(Figure 4)**. The operations team included the company's nominated transport manager[3], its sales and marketing managers, and its drivers and crew.

The engineering team worked from the company's vehicle maintenance garage located about 1 mile from Salthouse Dock. The director of engineering oversaw the day to day implementation of the company's maintenance management system and was TYD's designated person ashore[4]. The garage operated from 0800-2000 seven days a week using a two shift system, 4 days on and 4 days off. Each shift was led by an engineering manager and had three mechanics.

The majority of TYD employees had road transport backgrounds and none of the management team or technical staff had any commercial maritime experience prior to joining the company.

1.5.2 The fleet

TYD's DUKWs were certified by the MCA to operate on Category B[5] waters as Class V[6] passenger vessels. Pearlwild Ltd also held a Department for Transport (DfT) Traffic Commissioners' Standard National Licence that authorised TYD to operate its DUKWs as public service vehicles[7] on the road. Each vehicle was certified to carry up to 30 passengers and was required to have a crew of two. In accordance with local arrangements, each vehicle was also permitted to carry up to two babes in arms[8].

WQ1 and *WQ2* were both converted to APVs in 2001 and were almost identical. *WQ8* and *WQ4* were converted to APVs by a company on the south coast of England in 2000 and were originally operated in Glasgow, Scotland. When they first joined TYD's fleet in 2006 and 2009 respectively, their passenger space and canopy design were different to that of *WQ1* and *WQ2* and they could only carry 24 passengers. Their canopies were originally made from wood and had a retractable sun roof **(Figure 12)**. *WQ4* and *WQ8* were later converted to carry 30 passengers and the wooden canopies were replaced with steel ones, similar to those fitted to *WQ1* and *WQ2*.

[3] The appointment of a professionally competent transport manager was a statutory requirement under the Public Passenger Vehicles Act 1981. The nominated transport manager is the person responsible for the effective and continuous management of the transport activities of the company.

[4] The designated person ashore is the person who provides the link between ship's staff and shore staff to verify the implementation of the company's safety management system.

[5] UK Category B inland waters – *wider rivers and canals where the depth of water is generally 1.5m or more and where the significant wave height could not be expected to exceed 0.6m at any time*.

[6] Class V passenger vessel - ship engaged only on voyages in Category A, B and C waters.

[7] Public service vehicle – a vehicle with more than eight passenger seats used to transport people for profit.

[8] *Babes in arms* – children under the age of 1 year old.

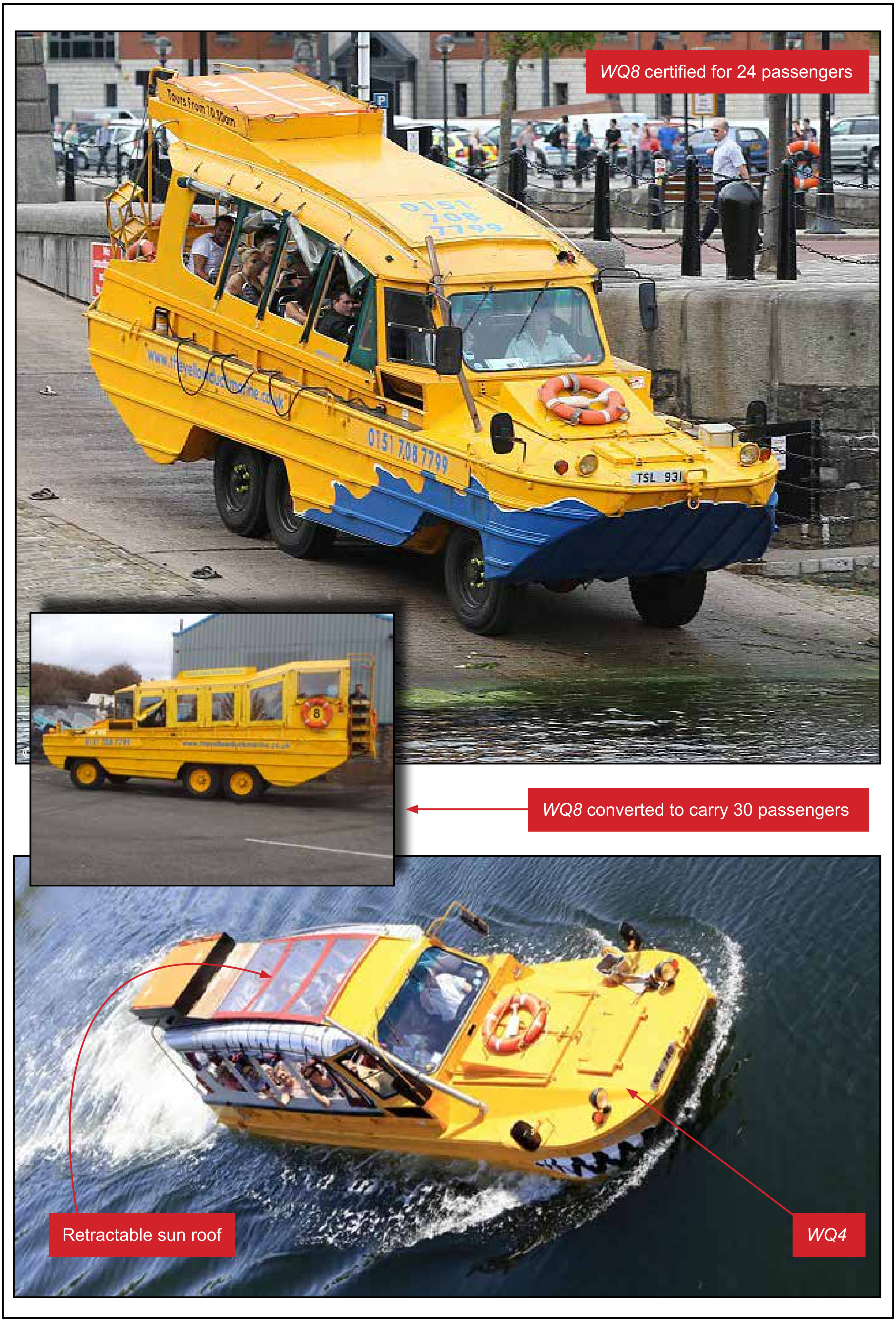


Figure 12: *Wacker Quacker 4* and *Wacker Quacker 8* before and after their conversion to carry 30 passengers

1.6 THE CREW

1.6.1 Master

The master was British and was 60 years of age. He had worked for TYD for 2 years and held a bespoke, operation-specific Boatmasters' Licence. He had been a master for a year, and prior to that he was a crewman and tour guide. He did not hold a public service vehicle (PSV) drivers' licence and therefore was not qualified to drive *WQ1* on the road.

1.6.2 Driver

The driver was British and was 51 years of age. He had worked for TYD for 4 months and held a PSV drivers' licence. He had been learning to drive the APVs on the water under the supervision of a master for 3 months and was working towards gaining his Boatmasters' Licence. Prior to joining TYD he drove commercial buses, coaches and heavy goods vehicles.

1.7 THE VEHICLE

1.7.1 The DUKW

Military DUKWs were designed during the World War 2 (WW2) for the purpose of making beach landings and transporting troops and equipment away from a beachhead. Although mechanically rugged, hull construction was simplified for the sake of an accelerated production schedule and the anticipated short life expectancy of the vehicles. Over 21,000 DUKWs were built in the US between 1942 and 1945, the majority of which were transported overseas.

The DUKW in its military configuration was built on a General Motors' 2½ ton 6x6 truck chassis (3 axles and 6 wheels) and had an overall hull length of 9.45m. It was equipped with a 6-cylinder GMC 270 gasoline (petrol) engine and had a 5-speed manual gearbox. The vehicle had a 2-man crew and could carry a payload of up to 2.3t of stores or 25 fully equipped combat troops. It had a maximum speed of about 50mph on land and just over 5kts on the water.

The vehicle had a three blade, clockwise rotating, phosphor-bronze propeller and a single spade-type rudder. The propeller shaft was supported externally in the water propeller tunnel by a cast steel v-strut **(Figure 13)**. The vehicle was left-hand drive and on land its front two wheels were steered in a conventional manner. The rudder was connected, by wire cables, to the main steering wheel and moved as the vehicle's two front wheels were turned.

The basic hull was of welded construction and was fabricated from a combination of 2mm, 2.4mm and 2.8mm thick cold-rolled carbon steel plates. The vehicle comprised five main compartments: bow (forward) compartment, engine compartment, driver's compartment (crew cab), cargo compartment and stern (aft) compartment. The driver's compartment, bow and stern decks, and the side coaming were manufactured as subassemblies and were bolted to the basic hull **(Figure 14)**. The original design took into consideration the interaction of road stresses on a truck chassis as well as the waterborne stresses on the hull. Interior bulkheads and reinforcement ribs provided extra rigidity **(Figure 14)**, but the hull had

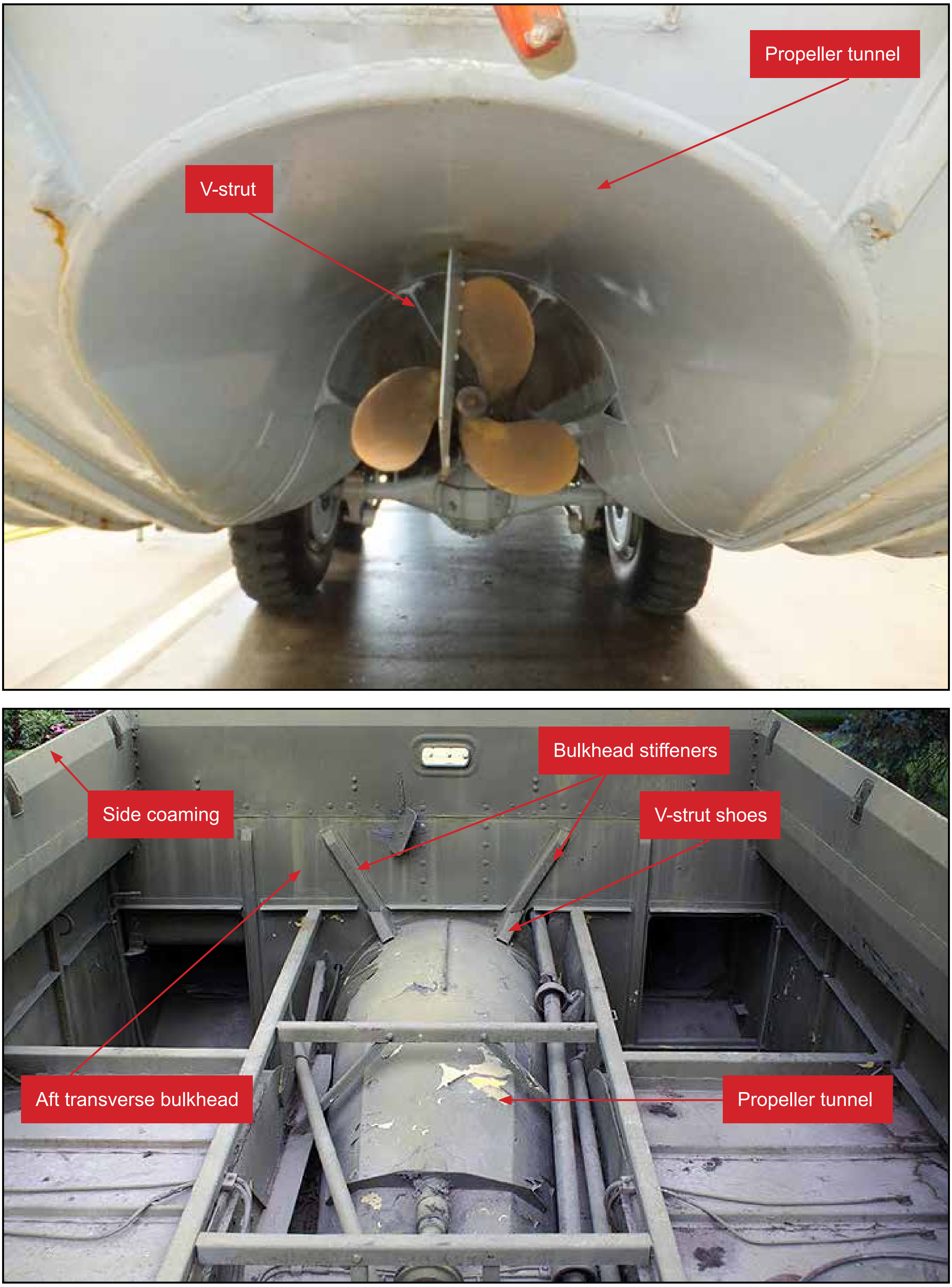


Figure 13: Propeller shaft v-strut support

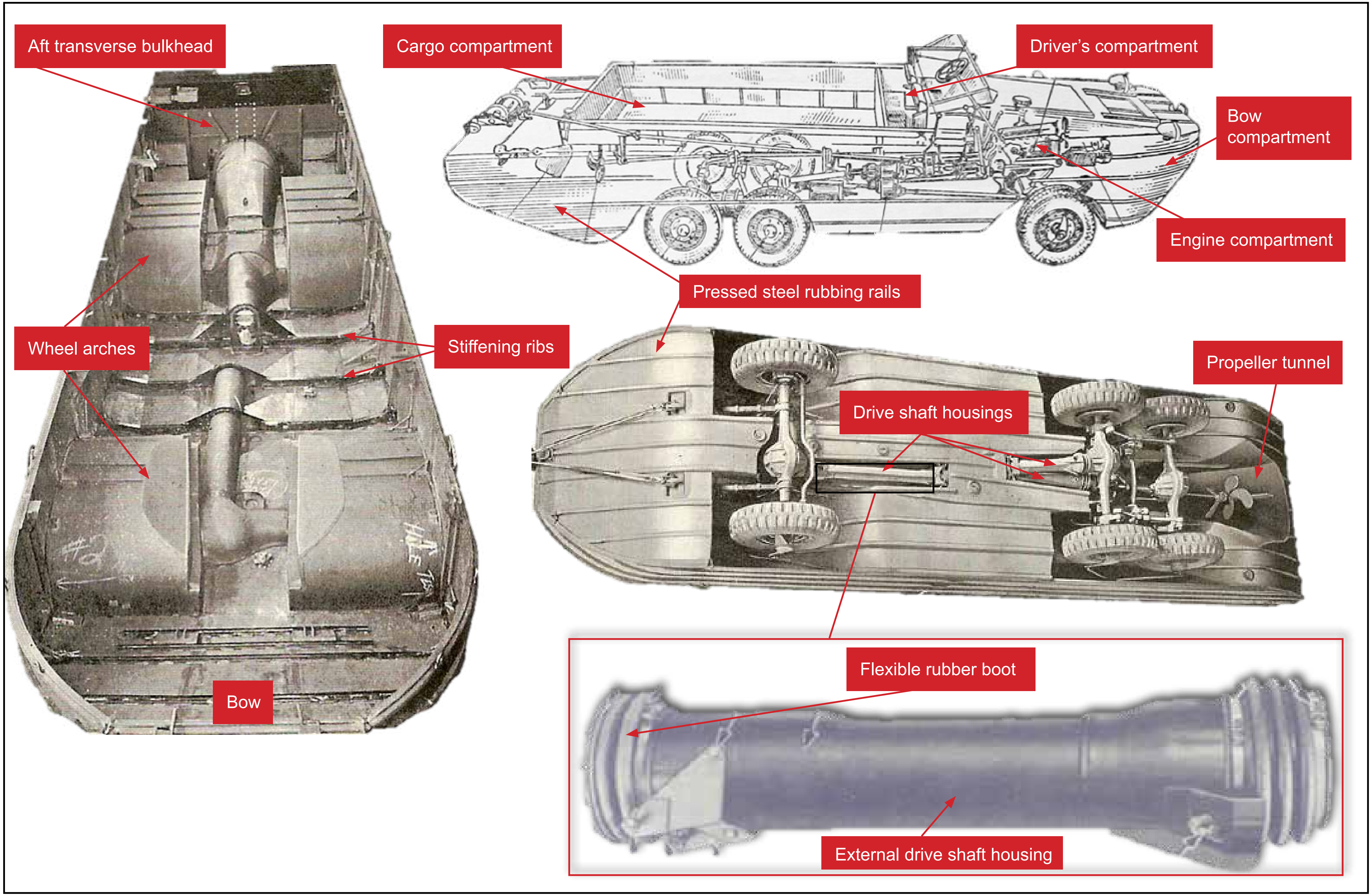


Figure 14: Original DUKW hull design and compartment layout

to flex with the chassis to prevent it failing during road use. Pressed steel rub rails were welded forward to aft along the outside of the hull (sides and bottom) to protect the shell plating from contact damage and to provide additional structural integrity.

The hull had three drive shaft tunnels: one for the propeller, one for the front wheel-axle; and one for the rear wheel-axles. The tunnels housed the hull penetrations for the propeller shaft and the wheel-axle drive shafts. The hull penetration for the propeller shaft was sealed using a standard marine stuffing box. The sealing of the hull penetrations for the wheel-axle drive shafts presented the designers with a more difficult challenge as the drive shafts needed to move up and down due to the action of the vehicle's suspension system. To solve the problem, the drive shafts were encased within watertight housings. The drive shaft housings permitted the size of hole in the hull necessary to provide the required vertical movement and elongation of the drive shaft. The drive shaft housings were sealed at both ends using flexible rubber boots **(Figure 14)**.

The hull had two transverse bulkheads. The aft transverse bulkhead separated the cargo compartment from the stern compartment and the forward transverse bulkhead separated the crew cab from the engine compartment. These internal bulkheads added structural strength but were not watertight. Any water that entered the hull was free to travel throughout its length. In order to remove water that might enter the hull over the deck coamings or through hull penetrations (due to seal failures or hull damage), the vehicle had two propeller shaft-driven de-watering/ bilge pumps and an emergency hand operated bilge pump. The larger capacity shaft-driven pump, known as the *Higgins* pump, was capable of discharging 200 gallons (1,100 litres) of water per minute. The capacities of the smaller shaft-driven pump and the hand operated pump was 50 and 25 gallons per minute, respectively. To operate the shaft-driven pumps, the propeller drive shaft had to be engaged; the higher the revolutions, the greater the pumping rate.

The DUKW was originally fitted with six drain plugs: 3 x 76mm diameter hull drain plugs and 3 x 38mm diameter drive shaft housing drain plugs. These allowed the crew to drain water and oil from the hull after exiting the water, and also provided access for greasing some of the drive shafts' universal joints (UJ). In addition to the drain plugs, four hull drain valves were fitted to later DUKW models.

1.7.2 *Wacker Quacker 1*

WQ1 was built in 1945 and in 2001 was converted for use as an APV. It was 9.45m long (hull length), 2.55m wide, had a road height of 4.1m and weighed 8.35t. In its APV configuration it could carry up to 30 seated passengers and was manned by a crew of two.

WQ1 was powered by a 6-cylinder, 4-stroke, naturally aspirated, Bedford 330 diesel engine with a manual gearbox. The chassis and basic hull were original and its drivetrain arrangements allowed the driver to manually select four or six-wheel drive, and engage the water propeller drive shaft ahead or astern. In four-wheel drive, power was delivered to the rear two axles, when six-wheel drive was engaged power was also delivered to the front axle.

Much of *WQ1*'s hull plate thicknesses were as original:

- 2.8mm at the bow and on the bottom at the stern;
- 2.4mm on the bottom in the centre; and
- 2mm on its sides.

The propeller and wheel-axle drive shaft tunnels were originally formed from 2.8mm and 2.4mm steel plate respectively.

The vehicle's original cargo compartment and stern deck was converted to provide the passenger compartment. The passenger compartment was decked with steel plates. The deck was not watertight and, although bolted down, the plates could be lifted to allow access for maintenance. Buoyant material was required to be fitted in the void spaces below the passenger deck and in several other locations within the vehicle.

The hull penetrations for the vehicle's wheel-axle drive shafts had been modified to allow the removal of the drive shaft housings and rubber boot arrangements. The original side coaming around the cargo compartment was extended aft to the transom and a watertight access door and boarding platform was fitted at the stern. A boarding ladder was fitted on the port side of the boarding platform.

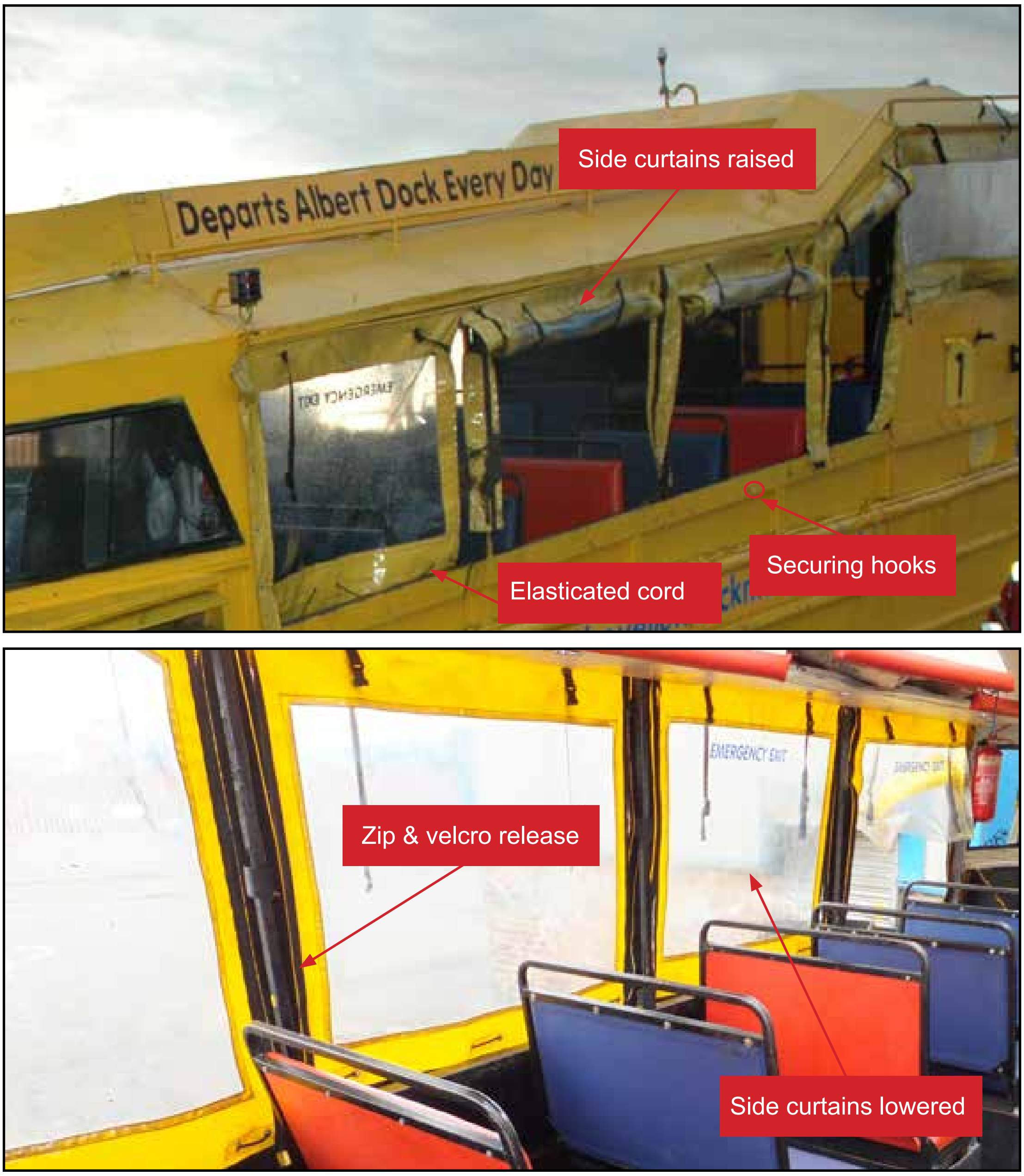


Figure 15: Liverpool DUKW side curtains

A steel canopy, with a solid Perspex sun roof and transparent plastic side curtains, was welded to the top of the passenger space side coaming. The side curtains were designed so that they could be rolled up and secured in the open position or closed using zips **(Figure 15)**. The zips were connected to individual window panels using Velcro so that the windows could be pushed open in an emergency. Elastic cords, which could be stretched over hooks on the outside of the side coaming, were fitted to the bottom of the side curtains to help hold them down while on the road.

The passenger compartment had 12 forward-facing 2-person bench-type passenger seats arranged forward to aft in two rows of 6 along its lower level, with a centre aisle. There were also two inward facing 3-person bench-type passenger seats on the raised platform at the back of the compartment **(Figure 7)**.

WQ1 had recently had its high capacity shaft-driven (*Higgins*) bilge pump removed, and was being operated with four electrically-driven bilge pumps. The bilge pump operating switches were located on the driver's control panel **(Figure 16)** and could be set to the *off*, *manual* or *automatic* position. When in automatic mode, the bilge pumps were started and stopped by their individual float switches. A warning buzzer sounded whenever the bilge pumps operated. There was also an emergency hand-powered bilge pump positioned on the starboard side of the passenger compartment behind the crew seats. In addition, seven external drain pipes with screw-threaded plugs were fitted to the bottom of the hull **(Figure 17)**. These were used instead of the original bottom plugs to drain water from the hull when on land.

TYD's vehicles were not fitted with any navigational aids and did not carry radio equipment. Each master carried a company mobile phone to allow them to communicate with the company's operations office and garage.

1.8 REGULATORY REQUIREMENTS

1.8.1 General

Amphibious sightseeing tours are considered to be a niche industry by both the maritime and road regulators. The modification of a DUKW for use as an APV presents a unique challenge as the vehicle must meet both land and maritime regulatory requirements. Any modifications made from the original design must take into consideration the impact on both the land and water aspects of the operation.

To operate on the road as a PSV, the converted DUKWs were classed as historical vehicles and were required to have a DfT *Certificate of Initial Fitness for Road Use* (COIF). As part of the COIF process, the DUKWs were inspected by the DfT's Vehicle and Operator Services Agency (VOSA)[9] and were subjected to a standard tilt test **(Figure 18)**.

When The London Frog Company first approached the MCA in 1998, the MCA treated the DUKW APVs as new vessels. As such, the MCA required owners to comply with the latest construction and stability standards set out in the Merchant Shipping (Passenger Ship Construction: Ships of Classes III to VI(A)) Regulations 1998. The standards required by these regulations were explained in the MCA's Merchant Shipping Notice (MSN) 1699 (M).

[9] At the time of initial certification, the COIF inspections were carried out by the DfT's Vehicle Inspectorate. In April 2014, VOSA and the DfT's Driving Standards Agency (DSA) merged to form the Driver and Vehicle Standards Agency (DVSA).

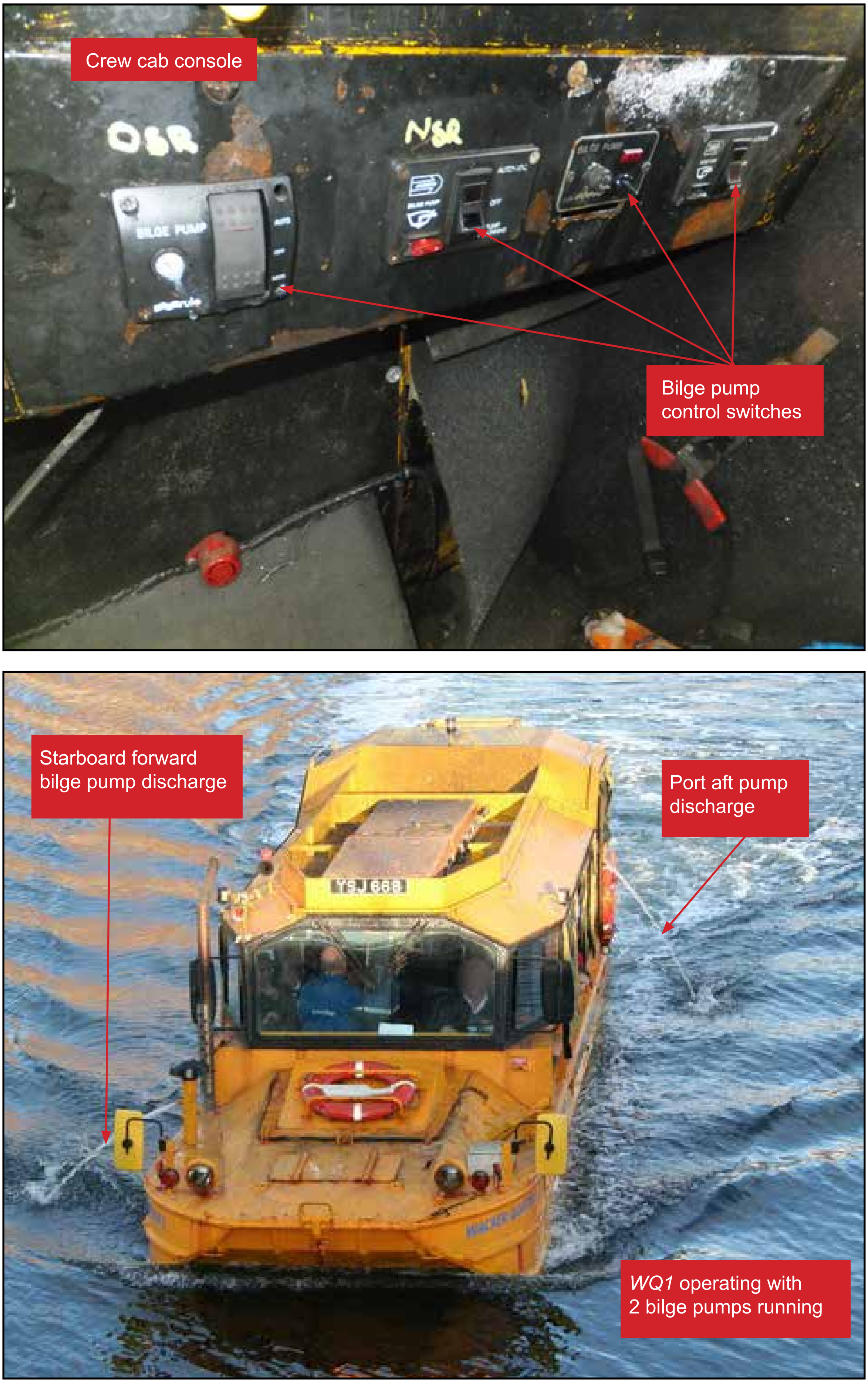


Figure 16: *Wacker Quacker 1* bilge pump controls

Figure 17: *Wacker Quacker 1* hull drain plugs

Figure 18: Road tilt test

In 2005, the MCA held a meeting at its headquarters to review its initial approval process for the converted WW2 DUKWs and other APVs. At the time, another DUKW (intended for use in Plymouth, England) had been submitted for approval but the local Marine Office had concerns over its hull construction; in particular, its hull plate thickness. According to the MCA's *Instructions for the guidance of surveyors*:

> *Unless justified by the use of special materials with supporting information to the satisfaction of MCA HQ, hull thickness of less than 3mm will not be accepted.*

The aim of the meeting was to establish what approval standards should be applied to future APVs, and what action should be taken with regard to existing DUKWs. It was established at the meeting that the records held on file at the MCA's Marine Offices were less than satisfactory and could not be used to confirm that the original DUKW APVs were properly approved when they were first allowed to operate in the UK. Following the meeting, MCA headquarters instructed its Marine Offices to ensure that all future APVs, and modifications to existing APVs, were approved to appropriate classification society rules. This meant that future converted DUKWs would require minimum hull bottom and side plate thicknesses of 3.5mm and 3.0mm respectively. Existing vessels were allowed to continue to operate on the understanding that special measures would be put in place; such as frequent inspections by operators, annual hull thickness checks by surveyors, and the application of epoxy coatings. A programme was already in place to increase the hull plate thickness of the London based vehicles to 3mm.

When Pearlwild Ltd purchased *WQ8* in 2005, the MCA's stance that all newly converted DUKWs had to comply with appropriate Classification Society rules, led the Liverpool Marine Office to refuse to certify the vehicle. The company appealed against the MCA's decision on the grounds that there were no class rules for APVs and its newly acquired vehicle had previously been issued a Class V passenger certificate. In 2006 the regulator overturned its decision and certified *WQ8*. Similarly in 2009, *WQ4* was certified to operate on the water in Liverpool's South Docks.

In 2010, the MCA published MSN 1823 (M), *Safety Code for Passenger Ships Operating Solely in UK Categorised Waters* and MSN 1824 (M), *EU Directive 2006/87/EC (as amended) – Laying Down Technical Requirements for Inland Waterway Vessels*. The mandatory safety code was developed in consultation with surveyors and the marine industry, and the technical standards superseded those set out in MSN 1699 (M). Although mandatory, the DUKWs were not required to meet the more robust technical standards set out in MSN 1823 (M) as they only applied to new ships (those that did not have a valid passenger certificate on the date the code came into effect).

In 2012, Pearlwild Ltd acquired a fifth DUKW but, as it had not been previously certified to operate as a Class V passenger vessel, the vehicle was required to meet the latest construction standards set out in MSN 1823 (M). Unable to meet the new standard, the company did not convert the DUKW to carry passengers and continued to operate with four vehicles.

1.8.2 Stability and survivability requirements

MSN 1699 (M) set out the stability requirements for undamaged vessels (intact stability) and the standards of survivability required for the damaged condition.

As the converted DUKWs had no internal watertight subdivision and their decks were not watertight, they were considered to be open ships. To satisfy the standards of survivability prescribed in MSN 1699 (M) for a Class V passenger vessel operating in Category B waters and carrying no more than 50 passengers the DUKW APVs had to achieve the heeling test standard described in Schedule 2, Section 3, and the buoyancy test standard described in Schedule 2, Section 4.

To meet the buoyancy test survivability standard the DUKWs were required to have sufficient buoyancy to remain afloat when fully flooded. To achieve this, the vehicle's effective residual intact buoyancy had to be at least 1.1 times its intact volume of displacement (110% buoyancy).

Compliance with the buoyancy test survivability standard could be demonstrated through practical flooding trials or by detailed theoretical calculations. In addition to remaining afloat in a fully flooded state, the vehicles were required to remain upright and stable.

MSN 1699 (M) also stipulated the minimum requirements for the construction of watertight bulkheads, bilge pumping systems, emergency electrical power arrangements, fuel systems, steering gear and hull penetrations. According to the regulations, *WQ1* was required to have at least one powered bilge pump (which could be engine-driven) and a hand bilge pump.

1.9 BUOYANCY FOAM

UK registered Class V DUKW APV operators used a combination of low and high density closed cell polyethylene foam to provide the required level of residual buoyancy. The foam used was supplied in sheet form and was individually cut to fit into nominated void spaces within the vehicle's hull. MSN 1699 (M) required owners to ensure that the buoyancy foam was:

- protected against deterioration;
- adequately secured against movement; and
- installed in such a way as to provide the greatest practicable contributions to the stability and survival of the ship in the flooded condition.

The original build specification for *WQ1*'s conversion also emphasised that the foam needed to be tightly packed and secured against movement, and not be in contact with moving parts.

The volume of buoyancy foam required to meet the buoyancy test survivability standard was dependent on the vehicle's weight and the inherent buoyancy provided by its tyres and other fixtures and fittings. The original amount of foam fitted into the Liverpool DUKWs is unknown. The only information found in the owner's records and the MCA's files relating to buoyancy foam requirements, was a set of calculations undertaken by Burness Corlett & Partners Ltd[10] on behalf of the London Frog Company in 1999. These calculations formed part of the London based company's initial submissions to the MCA and were based on a number of theoretical assumptions and a vehicle weight of 7.2t.

[10] Burness Corlett & Partners Ltd later merged with Three Quays Marine Services Ltd to form Burness Corlett Three Quays Ltd.

Following the sinking of *WQ4*, BCTQ calculated that *WQ2* required 9.7m^3 of buoyant material to be inserted into its hull in order to meet the damaged survivability standard. This was based on a weighbridge weight of 8.3t, passenger and crew weight of 75kg per person, and an estimated inherent buoyancy of 2.3t. The BCTQ report identified 14 locations **(Table 1)** where the buoyant material could be inserted. Its report also explained that its calculations were to be used for guidance purposes only, and that all vehicles in the fleet should be accurately weighed and an individual reserve buoyancy calculated for each.

Concerned that 9.7m^3 might not be sufficient to meet the survivability standard, and wanting to ensure that the DUKWs remained upright in the fully flooded condition, the MCA asked BCTQ to calculate the maximum space available for the insertion of buoyancy foam. Using a laser scan of a London DUKW (*Portia*), BCTQ identified 22 locations where, according to its calculations, about 12m^3 of buoyant material could be inserted. The revised calculations required an additional 1.1m^3 of foam to be fitted in the spaces below the passenger compartment and crew cab decks; almost half of which was designated to the centre void space. The revised volume in and around the engine compartment was almost doubled, from 1.56m^3 to 3.06m^3.

The MCA instructed TYD to pack 12m^3 of buoyancy foam into all its vehicles; this was the amount the MCA's Liverpool Marine Office understood had been fitted when it allowed the company to resume its operations on the water.

1.10 POST-ACCIDENT INSPECTIONS, TESTS AND TRIALS

1.10.1 MAIB and Maritime and Coastguard Agency inspections

Following the accident, MAIB inspectors and MCA surveyors from the Liverpool Marine Office examined *WQ1* and TYD's other DUKWs at the operator's vehicle maintenance garage. The MCA surveyors inspected the damage and oversaw the removal and measurement of the buoyancy foam from *WQ1*, *WQ2* and *WQ8* (*WQ4* was still being refitted at the time and did not contain any buoyancy foam).

WQ1's hull was found to contain about 6m^3 of buoyancy foam. Similar amounts were found in *WQ2* and *WQ8*. A large proportion of the foam removed was coated in oil and grease and there was evidence that some blocks of foam had melted as a result of contact with moving parts **(Figure 19)**.

The DUKWs were found to be in a poor material state: they were dirty; the internal paint coatings had lifted in many places; large sections of the vehicles' electrical wiring was unsecured and in poor condition; and many of the instrumentation gauges fitted to the consoles were found to be defective **(Figure 20)**.

There were a high number of external patch repairs and doublers[11] in place on *WQ1*'s hull. These were particularly evident in the propeller shaft tunnel **(Figure 21)**. There were two large holes in the propeller tunnel plating where the v-strut support shoes had been torn from the hull. One hole measured about 110mm x 140mm and the other about 220mm x 143mm **(Figure 21)**. The v-strut was hanging freely from the propeller shaft with its pressed steel support shoes still attached **(Figure 22)**. There were several other holes in the hull where the tips of the rotating propeller blades had made contact with the tunnel plating.

[11] The MCA's Instructions for the Guidance of Surveyors explains that: *doubling plates may be acceptable but normally only as a temporary repair in certain circumstances. For example, to increase the strength of plating and stiffeners but not bottom plating (excluding temporary repairs) and only if there is sufficient material in the parent plate to effect a good weld.*

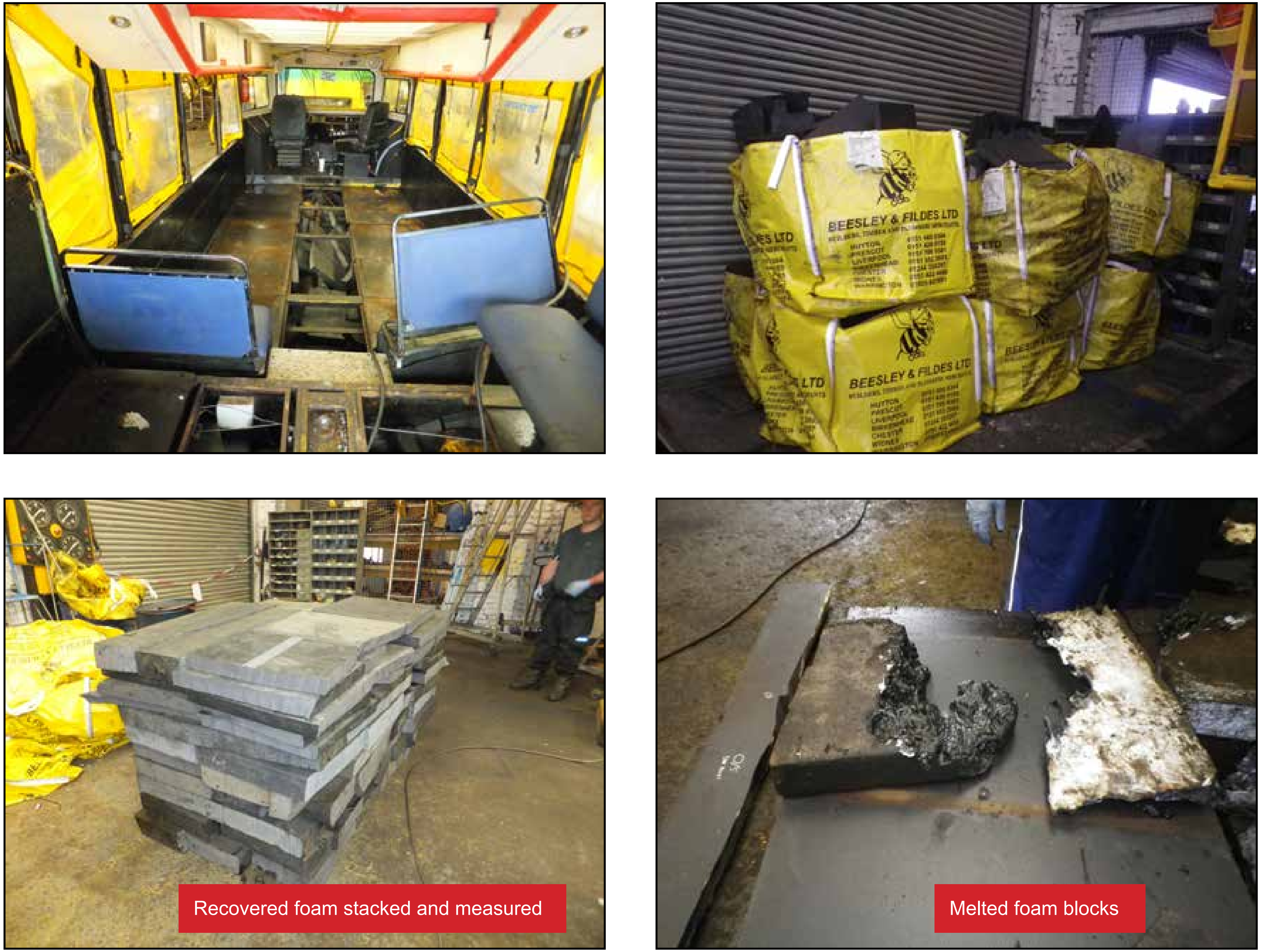


Figure 19: Foam removed from *Wacker Quacker 1*, *Wacker Quacker 2* and *Wacker Quacker 8*

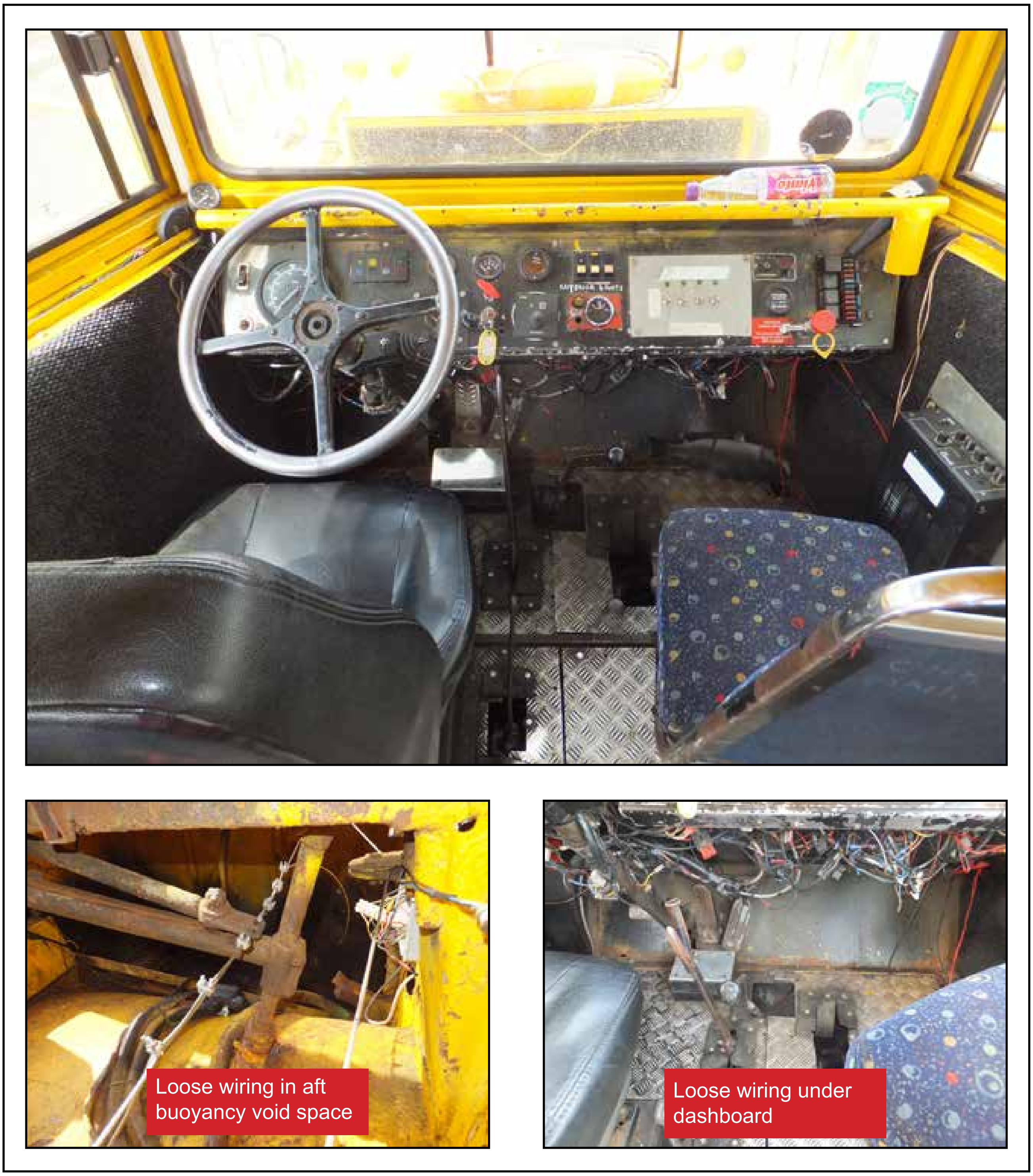


Figure 20: *Wacker Quacker 8* driver's cab instrumentation and electrical wiring

Figure 21: External patch repairs to the hull of *Wacker Quacker 1*

Figure 22: V-strut suspended from *Wacker Quacker 1*'s propeller shaft

1.10.2 Metallurgical analysis of hull plating

Two sections of the propeller tunnel plating and a section of the aft transverse bulkhead were cut from the hull of *WQ1* and were sent, along with the propeller shaft v-strut **(Figure 23)**, to The Test House (Cambridge) Ltd for metallurgical analysis. One of the tunnel sections included the two holes where the v-strut feet had been attached. The other section included large areas where it was evident that previous hull repairs had been carried out. The section of transverse bulkhead included the area where the v-strut support shoes had been attached.

Figure 23: Sections of propeller shaft tunnel and aft transverse bulkhead cut away and despatched for metallurgical analysis

At The Test House (Cambridge) Ltd, specimens of the hull plating were cut out, polished and subjected to micro-structural examination, chemical analysis and tensile tests. The metallurgical analysis report concluded that:

- The two U-section pressed steel reinforcement ribs welded to the forward face of the transverse bulkhead had suffered extensive corrosion wastage.
- The weld connecting the transverse bulkhead to the propeller tunnel plating had largely corroded away.
- The corrosion wastage had occurred sometime prior to the casualty and had compromised the hull's structural integrity; in particular the structure's ability to counteract any torsional stressing induced via the propeller shafting.
- The propeller tunnel plating in way of the stern compartment bulkhead and rudder stock had suffered widespread corrosion wastage, which had been addressed by multiple phases of fillet welded patch plate repairs (doublers).
- Evidence suggested that some of the hull repairs had not been fully effective, necessitating over-patching at some locations **(Figure 24)**.
- The original parent shell plating was low strength, low-carbon rimming[12] steel. This contrasted with the patch repair plates, which appeared to be of a more modern low strength fully killed[13] steel.

The metallurgical analysis report explained that production of the type of rimming steels seen in the samples was phased out in the 1970s. The report concluded that the base steel was either of original construction, or very old repairs dating back to the 1970s or earlier.

1.10.3 Stability tests and flooding trials

On 30 and 31 July 2013, the MAIB used *WQ1* to conduct a series of practical stability tests and flooding trials at the Cammell Laird shipyard, Liverpool **(Figure 25)**. In addition to MAIB staff and its shore contractors, the tests and trials were witnessed by representatives from the MCA, TYD, BCTQ and London Duck Tours Ltd (LDT).

The aims of the trials were to:

- verify the results of the theoretical buoyancy assessments conducted by BCTQ;
- identify any potential adverse effects associated with the insertion of buoyancy foam and;
- carry out a reconstruction of the 15 June 2013 flooding incident.

[12] Rimming steel, also known as drawing quality steel, is a type of low-carbon steel that has an excellent surface finish and is commonly used for cold-bending and cold forming.

[13] Fully killed steel has been processed so that there is no oxygen left in the steel. It is the strongest type of steel and is normally used in the construction of ships and vessels.

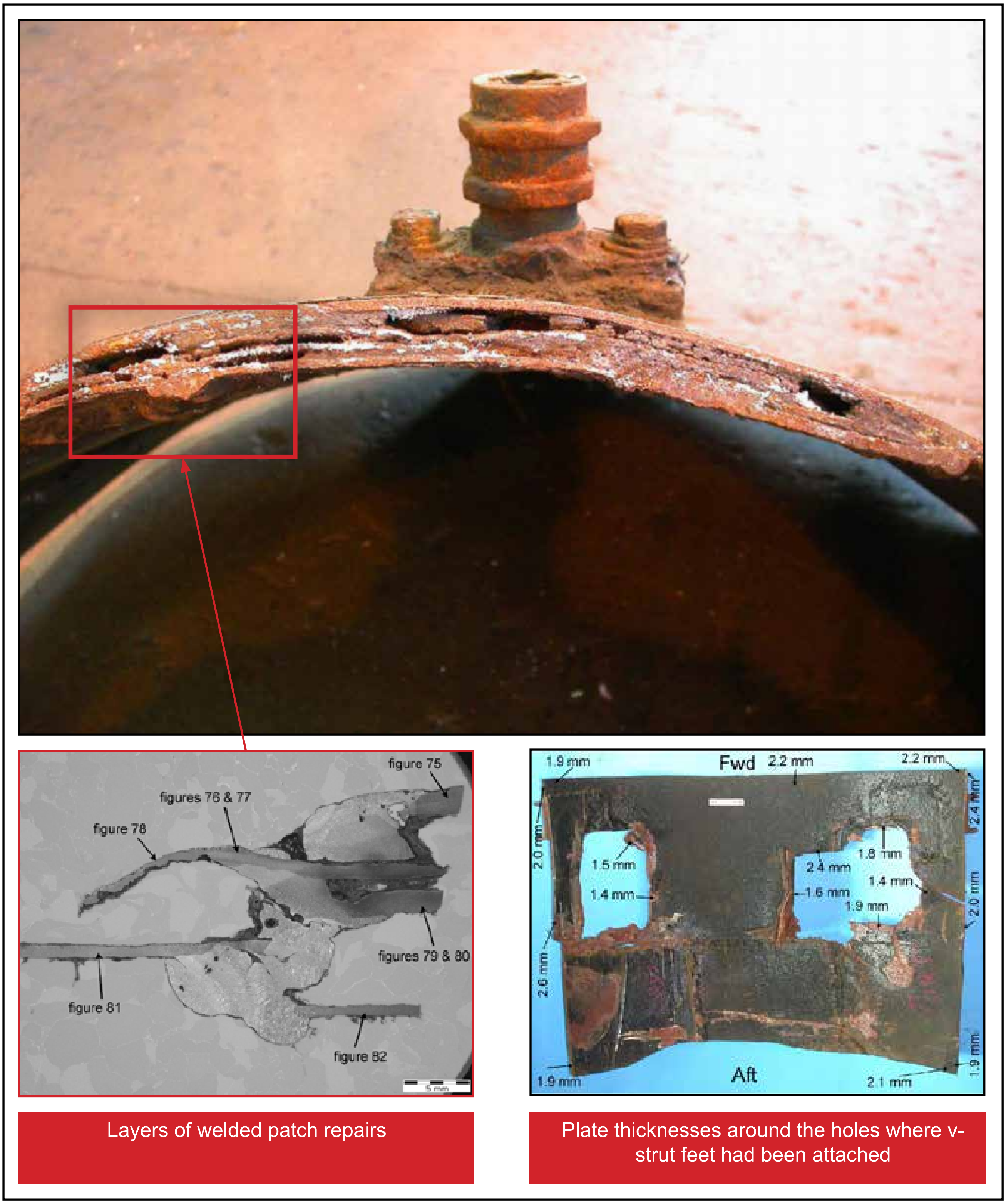


Figure 24: Analysis of propeller tunnel plating and welded repairs

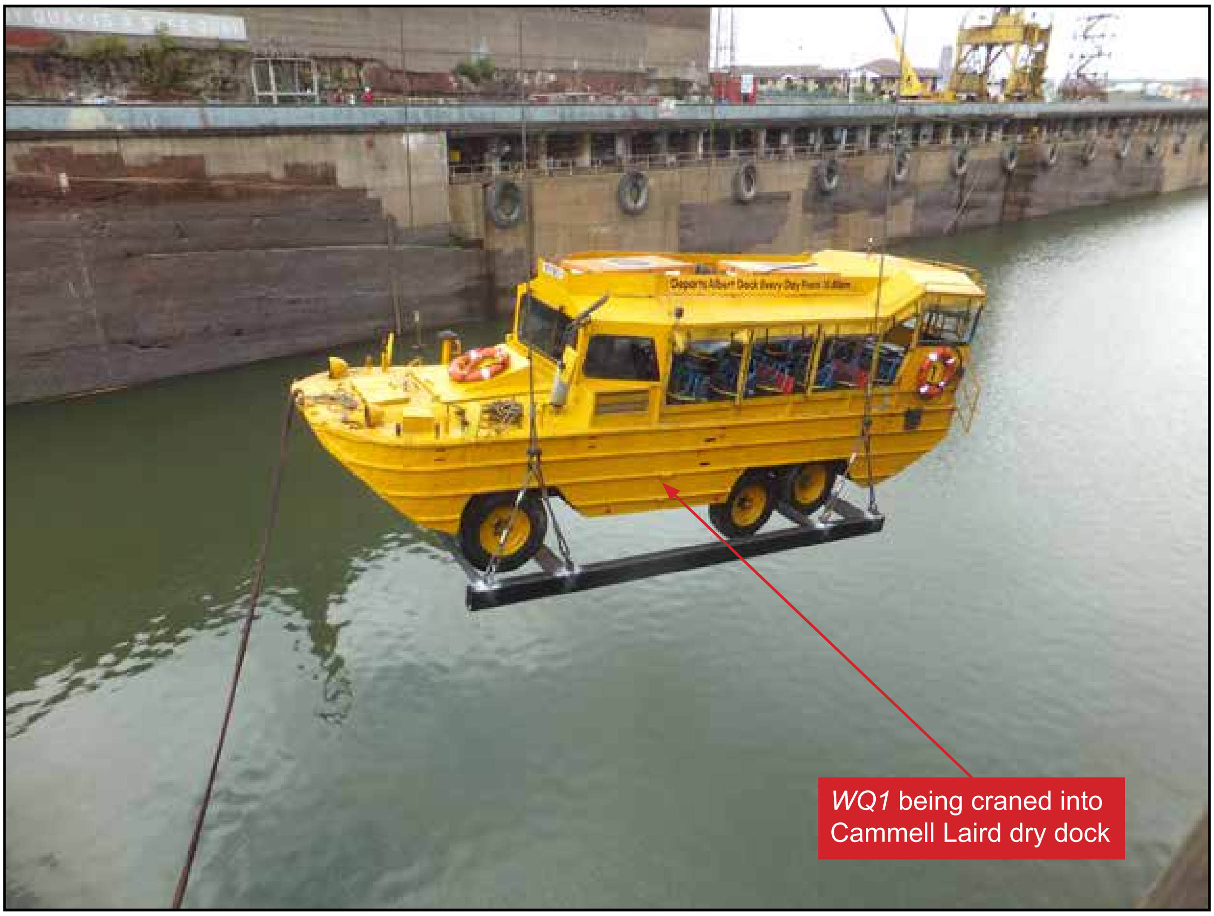


Figure 25: MAIB foam insertion trials and flooding reconstruction

Before the trials could take place, MAIB inspectors oversaw the repair of *WQ1*'s propeller tunnel and the insertion of buoyancy foam into the designated void spaces. A steel insert plate was formed and butt welded into the propeller tunnel, in place of the steel that had earlier been removed and sent for metallurgical analysis. Two 150mm diameter holes, designed to replicate those found in the hull after the sinking, were cut into the steel plate **(Figure 26)**. A short length of threaded steel pipe, with a blanking cap, was welded to each hole to allow the hull to be made watertight for the initial stability tests.

The buoyancy foam sheets used for the trials were individually measured and weighed before insertion. The foam was found to be about 5% denser, and therefore 5% heavier, than that given in its specification (33kg/m^3). When the high density foam recovered from *WQ1* was weighed, it was found to be 20% denser.

It took teams of 4 men 7 days (approximately 280 man hours) to insert the new buoyancy foam into the hull of the vehicle. The foam sheets were individually cut to size and tightly packed into the spaces identified for the insertion of 9.7m^3 of buoyant material in BCTQ's initial buoyancy assessment report **(Table 1)**. Care was taken not to compress the foam **(Figure 26)**. In order to ensure the maximum amount of foam was inserted, the operational requirements of the vehicle were not taken into account and foam was deliberately packed up against moving parts. The total quantity of foam fitted was 7.93m^3 **(Table 2)**; almost 2m^3 less than the calculated amount required to provide 110% buoyancy and 4m^3 less than that required by the MCA.

Figure 26: Hull preparations and foam insertion process

Location	Volume (m^3)
Aft buoyancy space	2.35
Aft port buoyancy space	0.38
Aft starboard buoyancy space	0.38
Port buoyancy space	0.84
Starboard buoyancy space	0.84
Centre void space	1.19
Port vent space	0.28
Starboard vent space	0.28
Port side shell and box	0.60
Starboard side shell and box	0.60
Forward buoyancy space	1.00
Two aft seat boxes	0.28
Twelve seat boxes	0.84
Driver and crew seats	0.10
Total volume	**9.96**

Table 1: Spaces identified by BCTQ as locations to fit buoyant material

Location	Volume (m^3)
Aft buoyancy space	1.6
Aft port buoyancy space	0.38
Aft starboard buoyancy space	0.33
Port buoyancy space	0.87
Starboard buoyancy space	0.84
Centre void space	1.24
Port vent space	0.28
Starboard vent space	0.28
Port side shell and box	0
Starboard side shell and box	0
Forward buoyancy space	1.00
Two aft seat boxes	0.24
Twelve seat boxes	0.87
Driver and crew seats	0
Total volume	**7.93**

Table 2: Volumes and locations of buoyancy foam inserted prior to MAIB flooding trials

The amount of foam that could be fitted in three locations was significantly less than the quantities calculated. The total amount of foam fitted in the aft buoyancy space was $1.6m^3$, which was 32% less than the $2.35m^3$ stipulated in the consultant's report. Had the operational requirements for the steering gear been taken into account, the quantity of foam fitted would have been further reduced. According to the consultant's report, TYD was required to fit 0.6m^3 of foam into the port and starboard side shell box panels. However, the maximum space available in each of the two spaces was no more than 0.06m^3. Although the shortfalls in the calculated volumes of foam were mainly attributed to these three spaces, had the vehicle's operational requirements been taken into account, the total amount of foam fitted would have been significantly less than the 7.93m^3 achieved.

On completion of the buoyancy packing process, *WQ1* was weighed to establish a baseline before weights were added to replicate its April 2013 weighbridge weight. Weights were then placed on the vehicle's seats to replicate the passenger and crew weight, and the fuel tank was filled with water. The remaining 2m^3 of buoyancy foam that could not be fitted into the designated void spaces was evenly distributed around the passenger compartment and secured in place **(Figure 27)**. *WQ1* was then craned into the water and a series of stability tests was carried out. Once the stability tests and an initial baseline flooding trial had been completed, the excess foam was removed and the main flooding trial was carried out. The trial was designed to simulate the best possible circumstances for the survivability of the fully laden vehicle and reconstruct the flooding sequence experienced on 15 June 2013.

With the caps removed from the two 150mm flooding pipes, *WQ1* was craned into the dock. It took about 5 minutes for *WQ1* to fully flood **(Figure 27)**. The DUKW assumed a starboard list but remained afloat with the water level settling about 50mm below the forward upper edge of the passenger space side coaming. *WQ1* was observed in this state for 30 minutes before it was craned out of the dock.

1.11 THE YELLOW DUCKMARINE SAFETY MANAGEMENT SYSTEM

1.11.1 *Safety Policy and General Safe Operational Procedures manual*

Pearlwild Ltd was required to produce a safety management system for its TYD operation that complied with the UK's Domestic Passenger Ship (Safety Management Code) Regulations 2001 (DSM Code). In accordance with the requirements of the DSM Code, the company produced its *Safety Policy and General Safe Operational Procedures* manual.

The manual comprised 15 sections and 3 annexes and had been updated several times over the years to reflect changes in company policy, procedures and key personnel. Section 4 of the manual set out the masters' responsibilities; Section 7 included the procedures relating to emergency preparedness; Section 10 contained the text for the passenger safety announcements; and Section 14 described the company's maintenance management system. The company's generic risk assessments were attached as an annex to the manual.

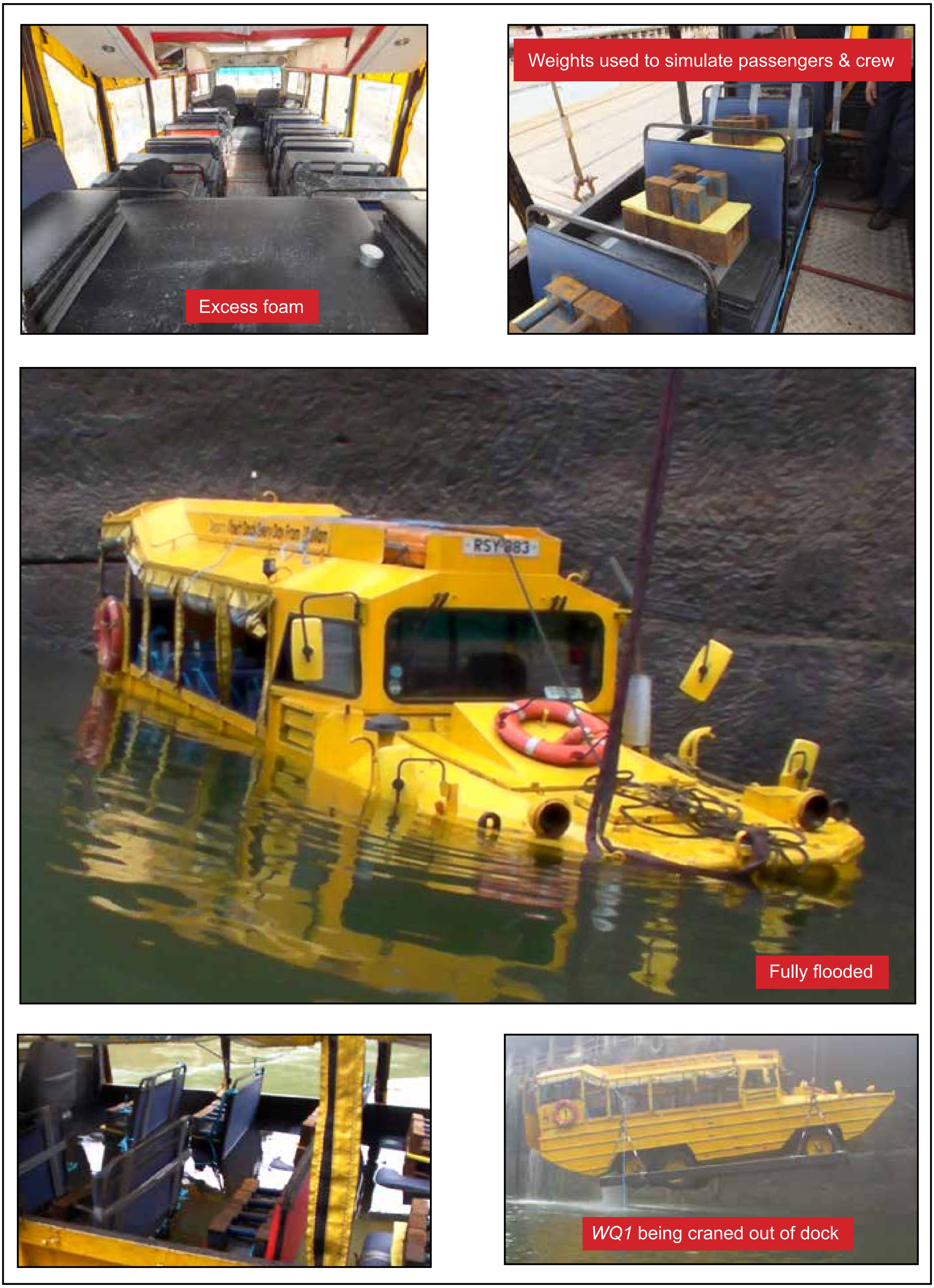


Figure 27: *Wacker Quacker 1* flooding reconstruction

1.11.2 Emergency preparedness

The procedures set out in Section 7 of the manual included those to deal with emergency situations such as *fire*, *abandon ship*, *man overboard*, *collision*, and *main propulsion or steering failure*. The documented procedure for *abandon ship* was:

- *On the command of the Master the crew person is to broadcast to passengers that there is an emergency and they are to prepare to abandon ship.*
- *The master is to raise the alarm to the Duty Manager via the mobile phone.*
- *The crew person is to assist passengers to put on lifejackets and release the passenger compartment side curtains.*
- *Launch floatation rafts – one either side of the vessel and attach to the vessel.*
- *Launch lifebuoys.*
- *Order all passengers into the water and to hold onto floatation rafts or lifebuoys.*
- *Release floatation raft lines.*
- *Master and crew person into the water, one each side of vessel.*
- *Check persons in the water.*
- *Administer first aid as required.*
- *Maintain lookout for vessels coming to assistance.*
- *Guide all in the water to the nearest landing point or dock wall ladder/safety chains.* [sic]

WQ1's master and driver had participated in the company's emergency drills and training programme and had experience of evacuating passengers onto pontoons and the slipway, but they were not familiar with the *abandon ship* procedure described in the manual.

1.11.3 Passenger safety announcements

Section 10 of TYD's safety management manual included two passenger safety announcements: one to be given prior to setting off from the pick-up point, and one to be given while stopped prior to driving down the slipway (pre-splashdown brief) **(Annex B)**.

The manual instructed the crew person to start the pre-splashdown brief by making a joke about getting off the vehicle. During the safety brief the master was expected to explain that there was a lifejacket on board for everyone; point out the location of the lifejackets; and tell the passengers that *'in the unlikely event that we need to use them'*, a member of the crew will instruct them on their use. The manual required passengers to be given the opportunity to choose to wear a lifejacket while on the water. The brief should also have explained the emergency escape routes, the method of releasing the side curtains, and the need to brace themselves prior to the splashdown. According to the manual, the crew person's initial water based commentary in Salthouse Dock should include details about the vehicle's life-saving equipment and various bilge pumping arrangements.

In earlier iterations of TYD's *Safety Policy and General Safe Operational Procedures* manual **(Annex C)** the crew person was required to give a practical demonstration of how to put on a lifejacket. The earlier briefs also made reference to buoyancy foam.

The pre-splashdown safety brief was usually given with the vehicle parked on the road opposite the Salthouse Dock slipway.

1.11.4 Pre-splashdown safety checks

Following the sinking of *WQ4*, the company introduced a procedure for the crew person to check that the hull drain plugs were in place prior to each splashdown. This was done during the master's safety brief. It was apparent from the South Docks closed-circuit television (CCTV) footage that this was not completed when *WQ1* was parked on the top of the slipway at 1530 on 15 June 2013.

1.11.5 Life saving appliances

WQ1 carried 2, 12 person buoyant apparatus[14] (solid foam-filled flotation rafts) and 4 lifebuoys[15]. This met the life saving appliances (LSA) requirements for 32 persons as set out in the Merchant Shipping (Life-Saving Appliances For Passenger Ships Of Classes III To VI(A)) Regulations 1999. The flotation rafts were stowed on the roof of the vehicle so that they could float free if the vehicle sank or capsized.

WQ2 carried the same LSA as *WQ1* but *WQ4* and *WQ8* carried one 20 person flotation raft and 4 lifebuoys. This did not meet the regulatory requirements as it only provided sufficient LSA for 28 people.

1.11.6 Personal flotation devices

TYD was required to provide sufficient personal flotation devices (PFD)[16] for everyone on board and ensure that they were readily accessible and their positions were clearly indicated. Up until 2012, TYD vehicles carried solid foam buoyancy aids, but at the time of the accident *WQ1* was carrying manually-activated gas-inflation lifejackets for its adult passengers (passengers weighing 32kg and over). The gas-inflation lifejackets provided 150N of buoyancy.

The lifejackets **(Figure 28)** were packed in transparent plastic bags and stowed in a box under one of the inward facing bench seats at the back of the vehicle. Solid foam lifejackets for children weighing less than 32kg were also provided. The lifejackets on board *WQ4* and *WQ8* were stowed in nets above the passenger seats **(Figure 28)**; when the DUKWs were inspected by the MAIB and MCA some of the lifejackets were still in their vacuum sealed packaging.

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[14] Buoyant apparatus - flotation equipment (other than lifebuoys, lifejackets and buoyancy aids).

[15] The buoyant apparatus may be substituted by lifebuoys up to a maximum of 60 per cent of the vessel's buoyant apparatus requirement, with each such lifebuoy being suitable to support two persons.

[16] Personal flotation devices are divided into the following two main classes: those which provide face up in-water support to the user regardless of physical conditions (lifejackets); and those which require the user to make swimming and other postural movements to position their face out of the water (buoyancy aids).

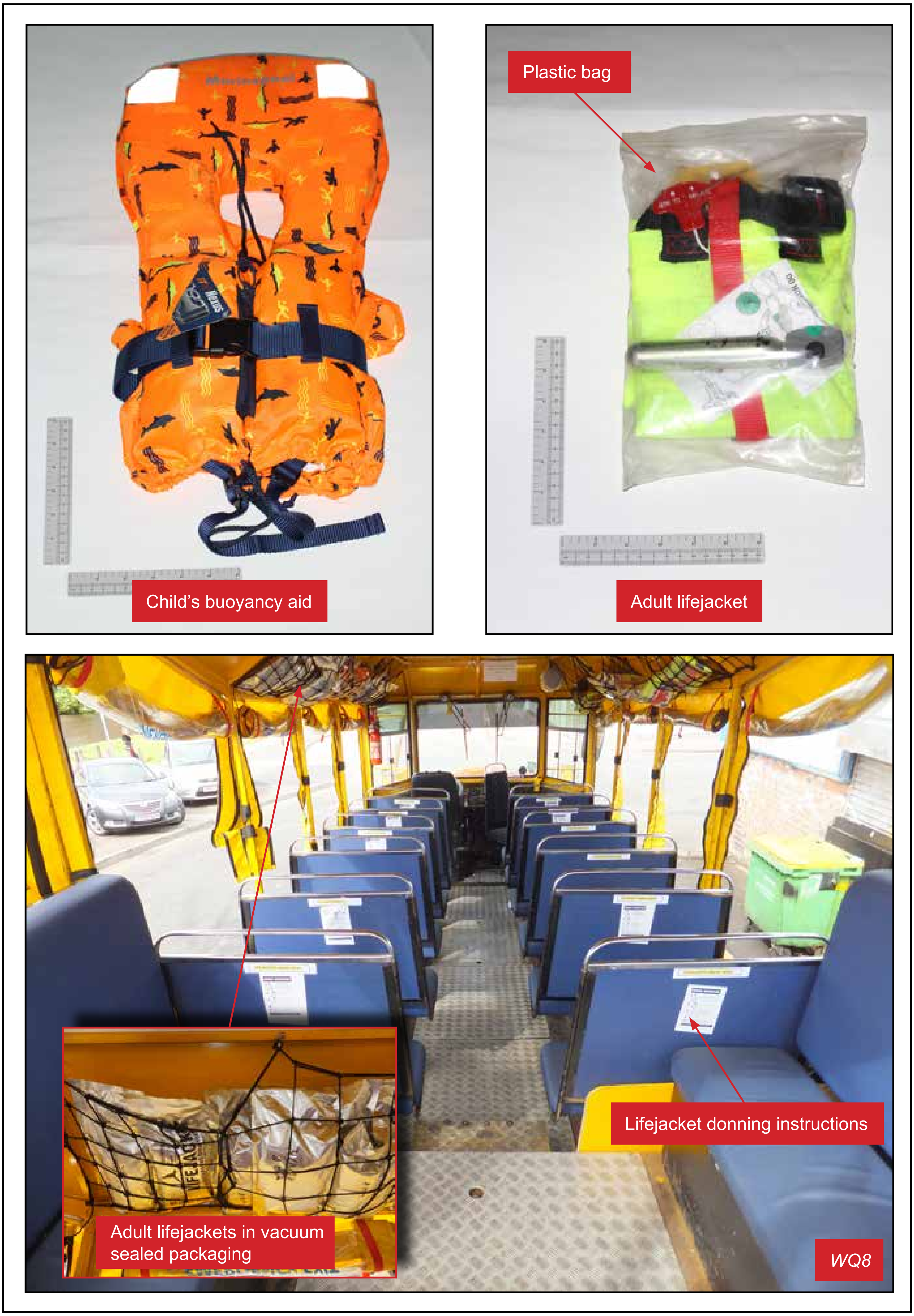

Figure 28: The Yellow Duckmarine lifejackets and buoyancy aids

1.12 THE YELLOW DUCKMARINE MAINTENANCE MANAGEMENT SYSTEM

1.12.1 Planned maintenance routines

To meet the requirements of the MCA and VOSA, TYD's garage staff followed an integrated passenger vessel and PSV planned maintenance regime. The paper-based maintenance management system allowed the mechanics to record the marine and road routines on a common set of maintenance sheets. The mechanics' daily, weekly and monthly maintenance routines were recorded on the company's A, B and C safety inspection and service sheets **(Annex D)**.

Any defects found during the inspections, and the actions taken to rectify or mitigate them, had to be recorded on the maintenance sheets. The mechanic or engineer who had completed the inspection, and carried out the service and repairs, was required to sign a declaration confirming that the work listed had been carried out and that he/she considered the vehicle to be roadworthy.

The company had also provided two daily checklists: one for the master/driver and one for the crew person/tour guide to complete **(Annex A)** prior to driving the vehicle out of the garage each day.

1.12.2 Unplanned breakdown repairs

As described in Section 1.12.1, the majority of the unplanned defect maintenance was recorded by the mechanics on the planned maintenance record sheets. The engineering managers also made contemporaneous notes in handover notebooks detailing any unusual defects that had been identified during their shift.

If the master called the garage to report a problem on the road or on the water, the engineering manager would deploy a mechanic, or team of mechanics, in the garage's breakdown response van. If a vehicle was immobilised on the water a second DUKW or the company's rescue boat might be used to assist.

A review of TYD's records established that the three most common problems on the water involved leaks due to hull corrosion, loss of steering and the failure to engage six-wheel drive. These problems occurred on a regular basis. The failure to engage six-wheel drive often resulted in the vehicle being unable to climb the Salthouse Dock slipway and the need to exit the water from Coburg Dock. On the day of the accident, *WQ2* and *WQ8* were both exiting the water from Coburg Dock.

On 14 June 2014, the day before the accident, *WQ1* lost steerage and had to be towed alongside. The buoyancy foam in the stern compartment had shifted, causing the rudder's tiller arm to jam. The garage team removed some of the buoyancy foam and repositioned the rest. According to the maintenance records, some of the additional foam fitted after the *WQ4* sinking was also removed from the bow compartment and the central void space because it had caused the engine to overheat and had made contact with rotating shafts. The MCA had been made aware of the overheating issue and had authorised the removal of some foam from the bow compartment.

1.13 VEHICLE SURVEYS AND INSPECTIONS

1.13.1 Maritime and Coastguard Agency

As a minimum, the MCA's passenger ship certificates had to be renewed at 5-yearly intervals. To ensure compliance with the applicable merchant shipping regulations for passenger ship construction, LSA and collision avoidance, the MCA surveyed each of TYD's vehicles annually. It also carried out annual inspections to check compliance with the requirements of the DSM Code. *WQ1* was last surveyed on 25 May 2013, following the modifications made as a result of the *WQ4* sinking.

In order to check the watertight integrity of the vehicle's hull the MCA surveyors carried out *'dip'* tests. The dip tests were carried out during each annual survey and involved the internal visual inspection of the hull with the vehicle in the water. On 15 February 2013, several pinholes were identified in *WQ1*'s hull during an annual survey dip test. The surveyor raised a deficiency and instructed the company to rectify the defect before allowing the vehicle back on the water. The company's maintenance records showed that similar corrosion related leaks were not uncommon and that the garage staff had frequently carried out their own dip tests.

The MCA also carried out random incognito inspections of the vehicles while they were in service. The most recent incognito inspection took place on board *WQ4* on 7 May 2012. Prior to splashdown, the crew made a point of telling the passengers that a wave of water would enter the vehicle through the door and wash through the passenger space. The surveyor noted that the crew did not close the aft doorway and, when challenged, they confessed that they had not done so for some time and did not have the doorway splashguard on board. On completion of the tour, the surveyor identified himself to the master and instructed him to cease operations and return to the garage. The surveyor wrote to the owner advising him of his observations. In his letter, the surveyor pointed out that the passengers were not given a lifejacket donning demonstration. He also warned that references made to the sinking of the *Titanic* and the film *The Poseidon Adventure* might cause offence to some passengers.

1.13.2 Vehicle and Operator Services Agency

VOSA carried out annual inspections of TYD vehicles at its commercial vehicle test centre in Liverpool. It also carried out random road side vehicle and garage based maintenance inspections.

In the 5 years previous to the accident, VOSA inspectors had carried out nine random inspections of TYD vehicles (8 on the road and 1 at the garage) and had issued prohibition notices to the company during seven of them. Five of the seven prohibition notices were issued for steering related defects. The garage based inspection identified that the company was not complying with the maintenance regime described in its statement of intent. The prohibition rate for TYD vehicles was 88%, which was almost five times the national average (18%). As a consequence, TYD was subject to a Traffic Commissioners' public enquiry, which had been scheduled to take place the week after the *WQ1* sinking.

1.14 INDUSTRY GUIDANCE AND INSTRUCTIONS FOR SURVEYORS

At the time of the accident, there were several other types of APVs being operated within the UK. There were also other converted DUKWs being operated as coded vessels, which were permitted to carry a maximum of 12 passengers, that had no buoyancy foam fitted, and did not meet the mandated damaged survivability standard. There was no industry body or an APV operators' code of practice to refer to for best practice.

The MCA and VOSA had worked together in the past to facilitate the safe introduction and operation of APVs. However, by 2013 both organisations were working in isolation and neither employed staff with designated APV expertise.

To facilitate surveys and ensure consistency, each MCA surveyor was supplied with the MCA's *Instructions for the Guidance for Surveyors*. This was a detailed document that covered the numerous areas surveyors could expect to encounter during vessel survey. The guide contained no specific guidelines relating to amphibious vehicles and no information regarding the installation of buoyancy foam.

1.15 PASSENGER QUESTIONNAIRES AND FEEDBACK

Following the accident, the MAIB interviewed several of the passengers and gathered additional feedback using passenger questionnaires. All those who were interviewed and those who completed the questionnaires raised concerns relating to the quality of the safety brief. Most said it was too quick, unclear and not taken seriously by the crew.

Of those who responded to the questionnaire (12 passengers), 62% thought that there were not enough lifejackets on board and half said they did not know how to put them on or operate them. The father of the 2 year old child struggled to put a buoyancy aid on his daughter because the waist strap was buckled shut **(Figure 28)** and had not been extended.

There was no positive feedback in the questionnaires relating to the actions of the crew and 38% of respondents said that the crew panicked. During interview, several of the passengers empathised with the crew and said that the speed with which *WQ1* flooded, the location of the lifejackets and the confined nature of the passenger space made it almost impossible for them to co-ordinate and control the evacuation process.

1.16 SIMILAR INCIDENTS AND ACCIDENTS

1.16.1 The Yellow Duckmarine

The MAIB's database contained records of two previous accidents involving TYD DUKWs. The first was a collision between *WQ2* and the TYD's passenger boat *Skylark* in Wapping Dock on 28 January 2013; the second was the sinking of *WQ4*.

The TYD's investigation into the collision between *WQ2* and *Skylark* found that the skipper of *Skylark* had been fooling around. He had deliberately manoeuvred his vessel at speed, in close proximity to *WQ2*, in order to create a wake and induce a roll on board the DUKW.

WQ4 sank while under tow very close to where *WQ1* sank **(Figure 2)**. Prior to the sinking, the vehicle had suffered a steering failure and had been towed onto a pontoon in Salthouse Dock by another DUKW. During the recovery, the crew stopped the engine and then realised that water was entering the bilges. Up to that point, the vehicle's chain-driven *Higgins* pump had been controlling the level of water in the hull. Once alongside, the passengers were landed and support arrived from the garage. Unable to restart the engine, they decided to use the rescue boat to tow the flooding vehicle to the Salthouse Dock slipway, and while under tow it sank. When *WQ4* was recovered from the dock it became apparent that one of the hull drain plugs was missing.

In addition to the lack of buoyancy foam, the MCA investigation into the sinking of *WQ4* highlighted that: the company's maintenance standards, the crew's knowledge of the vehicles' bilge systems, and the implementation of the company's procedures fell well short of reasonable expectations. As a result of its findings, the Liverpool Marine Office recommended that the findings of its investigation report be taken into account at a central policy level and that the Orpington Marine Office carry out a full review of the buoyancy arrangements on board the LDT vehicles.

During the initial stages of this investigation, it became apparent that several other accidents and incidents, which had not been reported to the MAIB or the MCA's Liverpool Marine Office, had occurred in the months leading up to the sinking of *WQ1*. Notably, in January 2013 an incident occurred that required passengers to be evacuated from a DUKW in Salthouse Dock, and on 1 June 2013 *WQ2* suffered a hull failure.

The first incident occurred after a steering failure. Instead of calling the garage and arranging to be towed to a pontoon, the master decided to attempt to manoeuvre his vehicle astern onto the slipway, using his front wheels to steer through the water. As his vehicle's rear wheels landed on the slipway the vehicle veered to port, fell off the concrete ramp, heeled over, and then wedged itself against the dock wall. The passengers were evacuated onto the dock side through the aft door.

Two weeks before *WQ1* sank, *WQ2* suffered a hull failure around one of the propeller shaft v-strut support shoes **(Figure 29)**. The failure was identified by the garage staff after the master had reported heavy flooding. The hull plating around the starboard v-strut foot was found to be heavily corroded, and the affected section of steel was cropped out and an insert plate was welded in place **(Figure 30)**. A doubler plate was fitted on the inside of the hull and sealed using a silicon based compound. The v-strut was bolted to the hull doubler plate, but the doubler plate was not connected to the aft transverse bulkhead. The MCA was not made aware of the repair.

TYD also had several incidents on the road. In September 2010, four passengers were injured and taken to hospital when a wheel fell off *WQ2* while it was being driven along a city centre street.

Figure 29: Similar hull failure discovered on board *Wacker Quacker 2* two weeks earlier

Figure 30: Hull repairs carried out by garage staff

1.16.2 *Beatrice*

On 31 March 2001, the London Frog Company's DUKW *Beatrice* suffered a hull failure[17] and started to take on water when its propeller was fouled by a large floating object. The master raised the alarm and then beached his vehicle on the north bank of the River, opposite Lambeth Fire Station. *Beatrice*'s 29 passengers were safely evacuated onto a London Fire Brigade vessel.

Beatrice suffered severe underwater damage. Its propeller shaft was bent, and the v-strut mountings had been ripped out of position. This caused the propeller tunnel plating to rupture and the hull to start flooding. The passengers were aware of the water entering the hull and took it upon themselves to start donning lifejackets. They had not been given a lifejacket demonstration and found it difficult to put them on, particularly as the straps had not been extended.

Damaged survivability and the use of buoyancy foam was not discussed in the MAIB investigation report of the accident.

As a result of the accident The London Frog Company replaced a large section of the propeller tunnel plating on all its vehicles with heavier gauge steel. It further reinforced the area around the v-strut mounting by welding and riveting an additional three layers of 2mm thick plate to the propeller tunnel **(Annex E)**.

The propeller tunnel plating was not strengthened on the Liverpool DUKWs. Following the sinking of *WQ4*, LDT had written to TYD to offer its help and make some recommendations to improve future safety. The strengthening of the propeller tunnel plating was one of the recommendations made in the letter. A copy of the letter was passed to the MCA at the time.

1.16.3 *Miss Majestic*

On 1 May 1999, the DUKW APV *Miss Majestic* **(Figure 31)** sank by the stern, with a driver and 20 passengers on board, during a regular sightseeing tour on Lake Hamilton, Arkansas, USA. About 7 minutes after entering the water the vehicle flooded, listed to port and rapidly sank by the stern in 19m of water. The driver and seven passengers escaped from the sinking vehicle and were rescued by pleasure boaters in the area. The remaining 13 passengers, 3 of whom were children, lost their lives.

The major safety issues identified in the US Government's National Transportation Safety Board's (NTSB) investigation report[18] related to:

- Vehicle maintenance
- Coast Guard inspections of *Miss Majestic*
- Coast Guard inspection guidance
- Reserve buoyancy, and
- Passenger survivability.

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[17] MAIB investigation report number 3/2001 – *Report on an investigation of a propulsion failure and subsequent beaching of the Class V amphibious passenger craft Beatrice on 31 March 2001, opposite the River Thames Fire Station, Lambeth.*

[18] NTSB/MAR-02/01 – Sinking of the Amphibious Passenger Vehicle *Miss Majestic*, Lake Hamilton, Near Hot Springs, Arkansas, May 1, 1999.

When *Miss Majestic* was inspected after she had been recovered from the lake bed, the investigators discovered that the rear drive shaft housing's aft rubber boot had worked loose because it had not been fitted correctly **(Figure 31)**.

Figure 31: Sinking of DUKW *Miss Majestic* on 1 May 1999

The US DUKWs were not fitted with buoyancy foam and relied on bilge pumps to provide damaged survivability. The NTSB report stated that the lack of reserve buoyancy needed to keep the DUKW afloat in the flooded condition was a flaw in its design when originally converted for passenger service and was a major contributory factor.

The NTSB investigation found deficiencies in the operator's maintenance procedures and the standard of US Coast Guard inspections. The report also identified problems with the accessibility of the lifejackets and highlighted that the passengers were not shown how to don them.

The NTSB report concluded that:

- The probable cause of the uncontrolled flooding and sinking of *Miss Majestic* was the failure of the vehicle operator to adequately repair and maintain the DUKW.
- *Miss Majestic* sank because the DUKW had no watertight bulkheads and no reserve buoyancy, and because its *Higgins* pump failed.
- The canopy was a major impediment to the survival of the passengers.
- The Coast Guard's inspection program for *Miss Majestic* was inadequate and cursory.
- The lack of Coast Guard guidance and training for the inspection of DUKWs contributed to the inadequate inspections.
- The wearing of lifejackets before the vehicle enters the water, where canopies are removed, would improve passenger safety.

Prior to publishing its report, the NTSB issued the following recommendation to the operators and refurbishers of APVs:

> *Without delay, alter your amphibious passenger vessels to provide reserve buoyancy through passive means, such as watertight compartmentalization, built in floatation, or equivalent measures, so that they will remain afloat and upright in the event of flooding, even when carrying a full complement of passengers and crew.*

Only one of the 30 APV operators in the US accepted this recommendation. The DUKW operators argued strongly that compartmentalization would introduce unacceptable levels of stress in the hull when operating on the road, and the insertion of buoyancy foam was not practical and would introduce many problems.

In 2001, the US Coast Guard published its Navigation and Vessel Inspection Circular[19] (NVIC) 1-01, *Inspection of Amphibious Passenger Carrying Vehicles*. The aim of the NVIC was to provide a guide to best practice for the inspection, operation and maintenance of APVs so that a consistent approach could be taken across all regions of the US. The guidance for hull surveys included a list of areas of concern, one of which was *the propeller shaft v-strut and its connection to the hull*.

The NVIC also provided guidance on the installation of buoyancy foam. The Coast Guard acknowledged that buoyancy foam could be used to augment subdivision, but warned that its installation generally aggravates maintenance problems by restricting access. The guidance also pointed out that, as foam deteriorates with age, periodic sampling is required to determine its condition.

When the NTSB report was published in 2002 it reissued its earlier recommendation but provided a list of recommended interim measures for operators who had yet to provide reserve buoyancy. These included:

[19] The US Coast Guard Headquarters issues NVICs to disseminate recommended policy, requirements, procedures, or guidance for Coast Guard marine safety personnel and the marine industry.

- Removal of canopies when on the water.

- Removal of unnecessary hull plugs and reduction in size of hull penetrations.

- Installation of independently powered electric bilge pumps to supplement the chain-driven *Higgins* pump (or similar capacity dewatering pump).

- Installation of high level bilge alarms.

- Compliance with the provisions of the US Coast Guard's NVIC 1-01.

When *WQ1* sank, most operators of original DUKW APVs in the US had implemented the interim measures prescribed in the NTSB report but had not met the reserve buoyancy standards recommended.

1.16.4 *DUKW 34*

On 7 July 2010, a barge (*The Resource*), being pushed by the tugboat *Caribbean Sea*, collided with the anchored APV *DUKW 34* on the Delaware River in Philadelphia, USA. *DUKW 34* sank and two of its 35 passengers drowned. The APV had suffered an engine cooling problem that the master had initially thought was a fire. The master stopped his engine and shut down the engine compartment before anchoring in the river. The cause of the collision **(Figure 32)** was attributed to a failure to maintain an appropriate lookout by the crew on board the tug that was pushing *The Resource*. The NSTB's investigation report[20] explained that *DUKW 34*'s master did not fully appreciate the risk of collision when he anchored in a navigation channel. The report also commented on the jocular nature of the master's safety brief and the fact that contrary to company procedure he did not don a lifejacket during the demonstration.

Figure 32: Collision between tugboat/barge *Caribbean Sea*/*The Resource* and *DUKW 34* on 7 July 2010

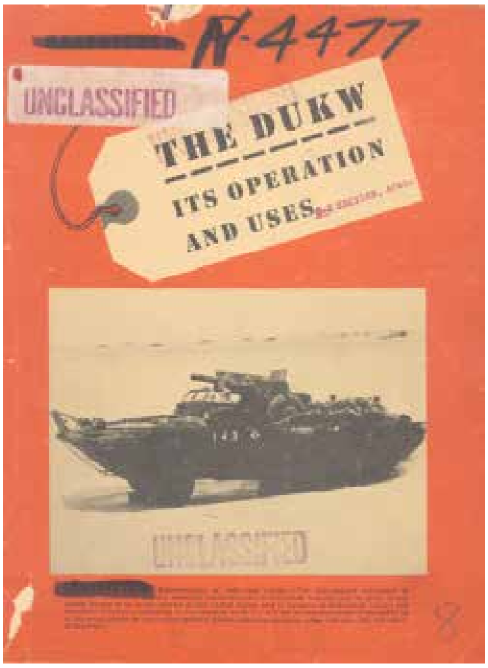
[20] NTSB/MAR-11/02 – Collision of Tugboat/Barge *Caribbean Sea/The Resource* with Amphibious Passenger Vehicle *DUKW 34* Philadelphia, Pennsylvania, July 7 2010.

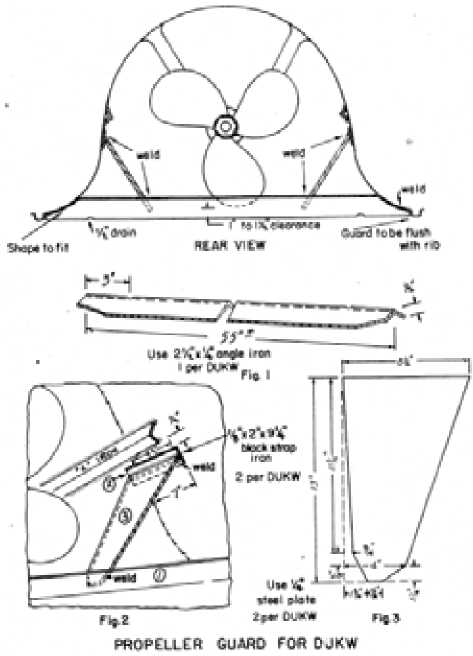
1.16.5 Lessons learned during World War 2 operations

In 1944, the US army reviewed the lessons learned during the first 2 years of DUKW operations in Europe and the Pacific and carried out a practical study. Its findings were used to produce a revised set of standing operating procedures and technical data, which was documented in *The DUKW, Its Operation and Uses* manual.

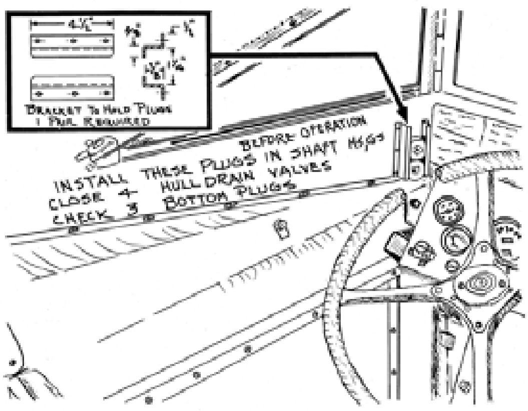
The manual provided up-to-date information designed to promote the most efficient utilization of DUKWs, and prescribed several modifications to reduce the likelihood of vehicle breakdowns, flooding incidents and fires. The modifications included the retrofitting of bottom plug stowage racks in the driver's compartment, and propeller guards **(Figure 33)**.

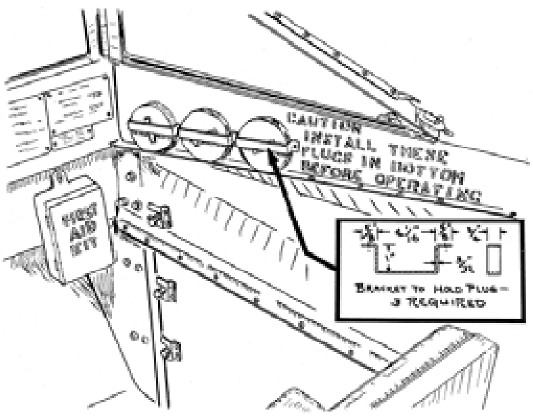
The manual warned of the dangers of entering the water without first checking the bottom plugs are in place, and instructed the DUKW engineers to paint warning notices next to the plug stowage racks. The army had discovered that the DUKWs were particularly susceptible to propeller fouling and provided instructions for the fitting of propeller guards.





Propeller guard for *DUKW*





Drain plug stowage and caution notices

Figure 33: World War 2 operations manual

SECTION 2 – FACTUAL INFORMATION CLEOPATRA

2.1 PARTICULARS OF *CLEOPATRA* AND ACCIDENT

SHIP PARTICULARS	
Vessel's name	*Cleopatra*
Flag	UK
Certifying authority	Maritime and Coastguard Agency
Vessel type	Class V passenger vessel
Vehicle chassis number	3536279
Vehicle type	DUKW amphibious passenger vehicle
Year of build	1945 (converted to APV in 1999)
Registered owner	London Duck Tours Ltd
Construction	Steel
Hull length	9.45m
Length overall	10.35m
Width overall	2.48m
Height of canopy (from the road)	3.8m
On road weight	8.66t (2009 weighbridge weight)
VOYAGE PARTICULARS	
Port of departure	Lacks Dock, London
Port of arrival	Lacks Dock, London
Type of voyage	Sightseeing tour, tidal river estuary
Manning	2
MARINE CASUALTY INFORMATION	
Date and time	29 September 2013 at about 1154
Type of marine casualty or incident	Very Serious Marine Casualty
Location of incident	River Thames near Tower Gardens, Westminster
Place on board	Engine bay, shaft tunnel and passenger compartment
Injuries/fatalities	Nil
Damage/environmental impact	Nil
Ship operation	Sightseeing tours
Voyage segment	Transit
Environment	Daylight; fair; light winds; ebb tide stream < 1.75 knots
Persons on board	30 (2 crew + 28 passengers)

2.2 BACKGROUND

On 20 June 2013, two surveyors from the MCA's Orpington Marine Office attended the LDT fleet maintenance garage to determine the volume of buoyancy foam present in the LDT vehicles. The buoyancy foam was removed from the randomly selected DUKW *Rosalind* and weighed. Having estimated the foam density, the surveyors calculated that the vehicle had contained about 6m^3 of foam. A similar exercise carried out on DUKWs *Titania* and *Elizabeth* determined that they contained about 5.5m^3 and 5.8m^3 of foam respectively.

Following discussions with the MCA, LDT suspended its waterborne operations and undertook to increase the levels of buoyancy foam fitted to its vehicles to 9m^3. On 1 July 2013, the MCA instructed LDT to further increase the volume of buoyancy foam in each vehicle to 10.6m^3.

On 7 August 2013, following the analysis of the results of the practical trials conducted by the MAIB in Liverpool **[Paragraph 1.10.3]**, the MAIB made a recommendation (2013/221) to the MCA:

> *require operators of DUKW passenger vessels in the UK to demonstrate that they are able to provide 110% effective residual intact buoyancy in their vessels, and where buoyancy foam is fitted for this purpose, **the quantity installed is measured by volume** and the **foam does not impede the operation or maintenance of key equipment**.*

By this time, six of LDT's vehicles had been returned to the water. *Cleopatra* was re-packed with foam between 12 and 22 August and, on 24 August 2013, returned to the water with 10.6m^3 of buoyancy foam on board. On 24 September 2013, a team of MCA surveyors arrived at the LDT garage to witness and assess the insertion of buoyancy foam into DUKW *Portia*.

2.3 NARRATIVE

At 1110 on 29 September 2013, DUKW *Cleopatra* **(Figure 34)** left its Southbank departure point and commenced a standard tour of the Westminster area of London, England. On board were the driver, the tour guide and 28 passengers. Upon completion of the on-land portion of the tour, the vehicle arrived at Lacks Dock slipway, Vauxhall, where the driver handed control of the vehicle to its master for the river section of the tour. While the driver and master carried out their routine handover inspection, the tour guide gave the passengers a pre-splashdown safety brief, which included a demonstration of how to don the passenger buoyancy aids.

At 1145, the master drove *Cleopatra* down the slipway into the River Thames and headed downriver. As *Cleopatra* approached Lambeth Bridge **(Figure 35)**, the tour guide noticed an unusual smell. He told the master, who then checked that the vehicle's handbrake was disengaged. The smell soon dispersed and the master continued on with the tour. When *Cleopatra* approached Westminster Bridge the master turned the vehicle around and commenced the return journey upriver. As *Cleopatra* passed the Houses of Parliament, the tour guide noticed the unusual smell again, and saw wisps of light grey smoke coming from the engine compartment's cooling air inlet **(Figure 36)**. At about the same time, some of the passengers noticed light grey smoke rising from the floor close to the tour guide's left leg.

Initially, the master thought that the smoke might have been caused by an engine exhaust problem and, as a precaution, he angled *Cleopatra* towards the shore. The tour guide then made an announcement to the passengers informing them that there was a problem with the vehicle. The smoke increased in thickness, darkened in colour and began to billow out of the engine compartment's starboard extraction fan vent **(Figure 36)**. At this point a passenger towards the rear of the vehicle shouted, "*Fire! Fire!*"

Image courtesy of Philip Bisset

Figure 34: London Duck Tours amphibious passenger vehicle *Cleopatra*

Reproduced from Admiralty Chart BA 3319-0 by permission of the Controller of HMSO

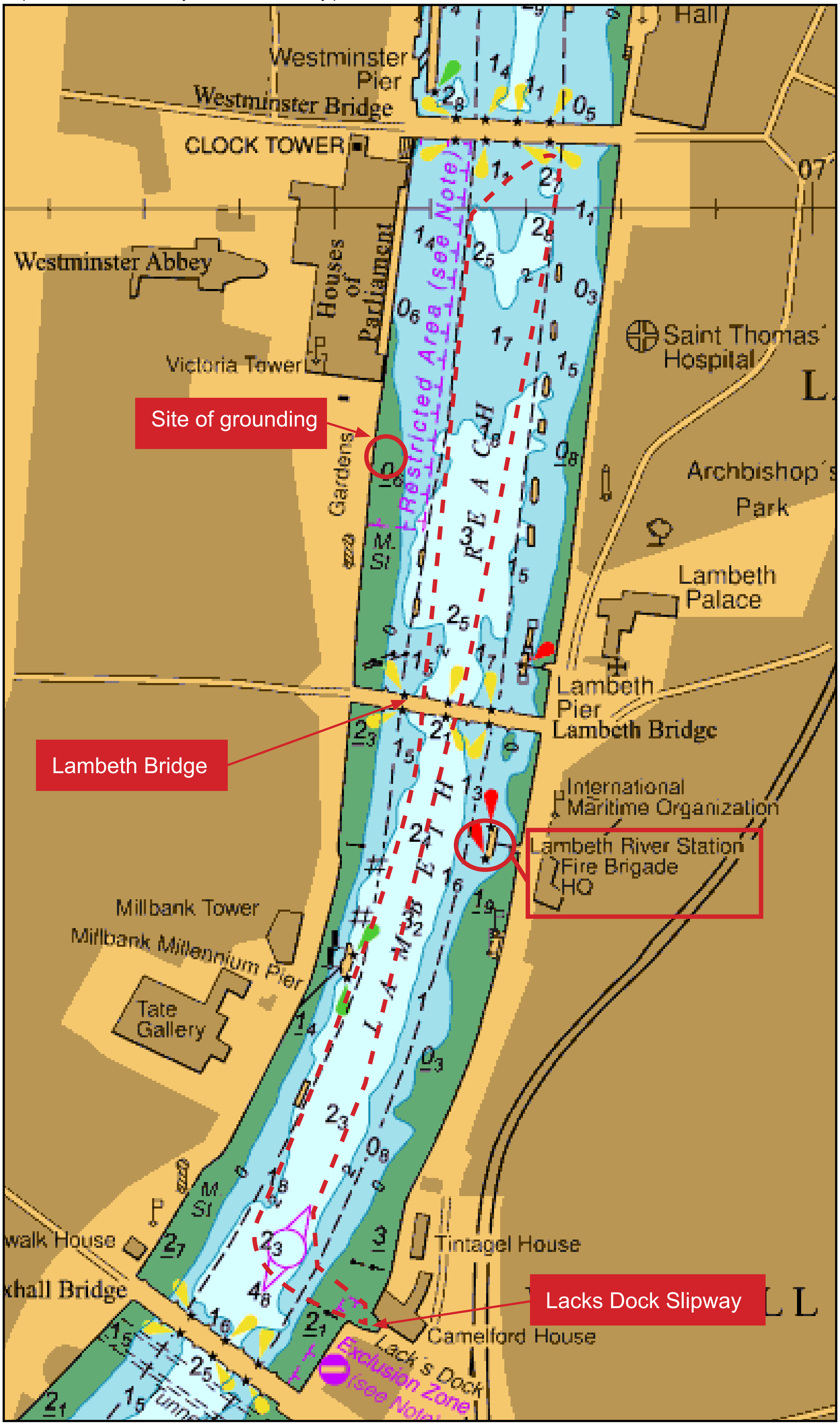


Figure 35: The waterborne section of the London Duck Tours sightseeing routes

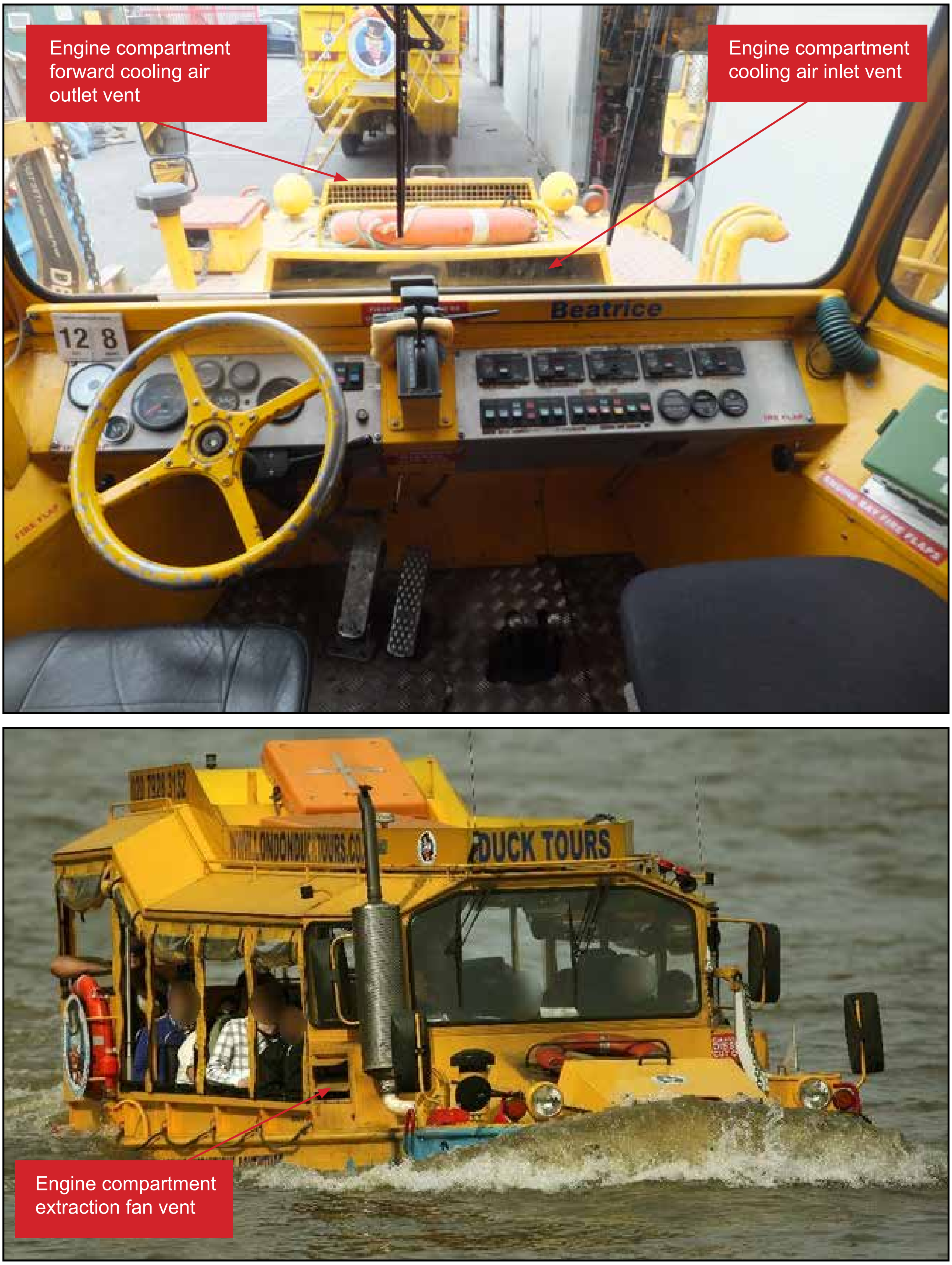


Figure 36: Engine compartment cooling air vents on a similar London Duck Tours vehicle

At 1154:20 the master called the Port of London Authority (PLA) Vessel Traffic Services (VTS) by radio and asked for the assistance of the fire brigade. Before VTS could acknowledge the call, the radio on board *Cleopatra* ceased functioning. Nevertheless, the brief but anxious radio call had been heard by numerous river craft operators and an unknown source advised the PLA VTS by radio that *Cleopatra* was on fire close to the Houses of Parliament. The transmission was overheard by Thames Coastguard, and it immediately notified the London Fire Brigade (LFB) and the Royal National Lifeboat Institution's (RNLI) Tower Pier and Chiswick lifeboat stations. The coastguard then adjusted the position of a Westminster CCTV camera and began to monitor the situation on its visual display screen.

The master continued to steer *Cleopatra* towards the shore until the vehicle's front wheels touched bottom by Victoria Tower Gardens **(Figure 35)**. Once on the mud, the master kept the propeller engaged ahead to keep the craft pressed against the shore. As the fire escalated **(Figure 37)**, many passengers fled in panic towards the rear of *Cleopatra*, some grabbing buoyancy aids as they did so. Other passengers climbed out of windows when they realised that this was their easiest and quickest escape route. The passenger who had first raised the alarm succeeded in partially opening the rear door but was quickly pushed aside by other passengers, separating him from his family.

The tour guide physically pushed his way through the passengers with the intention of lowering the boarding ladder to assist evacuation. However, the weight of the escaping passengers standing upon the raised port ladder prevented the guide from untying the securing rope and lowering the ladder. Due to the barrier presented by the partially open door on the boarding platform, people had difficulty accessing and lowering the starboard ladder, resulting in many having to jump into the water. As people dispersed from the boarding platform, the starboard ladder was eventually lowered and the door fully opened, allowing the last evacuees to descend the stairs to the water.

The master was the last person to leave the vehicle, and only did so after confirming that the passenger compartment was empty of people.

Within 3 minutes of the master's incomplete radio transmission, three rigid-hulled inflatable boats (RIB) from the Thames RIB Experience Company[21] arrived on scene. By this time, some passengers had managed to wade to shallower water. Some of *Cleopatra*'s passengers abandoned directly onto the RIBs and the rest were recovered from the water **(Figure 37)**. Within 2 minutes of their arrival, all passengers and crew had been recovered onto the RIBs.

At 1159, the LFB fireboat, *Fire Dart*, arrived at the scene, closely followed by a land appliance on the riverbank, adjacent to *Cleopatra*. The fire was quickly brought under control and, by 1201, it was extinguished **(Figure 37)**.

The rescue vessels carried the survivors to LFB's Lambeth River Fire Station pontoon where all 30 were disembarked and met by ambulance staff. Three of the passengers were taken to hospital for further medical examination, but were discharged later that day.

[21] The Thames RIB Experience Company operated high speed RIB tours for tourists on the River Thames.

Images courtesy of Daily Mail online © Tony.Margiocchi Bar Craft media

Figure 37: Abandon ship and rescue sequence

2.4 ENVIRONMENTAL CONDITIONS

It was a dry day, with a moderate (11-16kts) east-north-easterly wind and a neap tide. The depth of water between Lambeth Bridge and Westminster Bridge at high water (0915) was 5.2m. At the time of the accident, the ebbing tidal stream adjacent to the Houses of Parliament at mid-stream was about 1.75kts.

2.5 LONDON DUCK TOURS

In November 2001, the London Frog Company Ltd ceased trading and went into liquidation. In May 2002 Capital Frogs Ltd, who had taken ownership of the liquidated company's assets, re-introduced the APV sightseeing tour service. In 2004 Capital Frogs Ltd was rebranded and changed its trading name to London Duck Tours. Between 2006 and 2012 LDT increased its fleet of DUKW APVs from 5 to 9. LDT's converted DUKWs were certified by the MCA to operate during daylight hours on Category C[22] waters as Class V passenger vessels.

At the time of the accident, LDT employed 74 people, including office staff, fleet maintenance operatives, road drivers, river masters, tour guides and freelance staff. The company had an office and a booking shop in Waterloo, close to the London Eye, and a fleet maintenance garage in Battersea.

LDT's route covered the Westminster area of London and its guided sightseeing tour lasted about 1 hour, which included 25 minutes on the River Thames. The passenger pick-up and drop-off point was located on Chicheley Street, directly in front of the company's booking shop. The vehicles entered and exited the river at the Lacks Dock slipway, Vauxhall, and cruised as far as Westminster Bridge **(Figure 35)**.

2.6 THE CREW

The LDT vehicles were crewed by two people at all times. On the road, the vehicle was manned by a driver (PSV licence holder) and a tour guide; on the river, it was crewed by a master and a tour guide. The driver handed the vehicle over to the master at Lacks Dock prior to the vehicle entering the water. During the handover the crew were required to carry out a set of pre-entry checks and deliver the safety brief to their passengers.

2.6.1 Master

Cleopatra's master was British and was 71 years of age. He had been a waterman[23] and lighterman[24] on the River Thames for most of his working life. He had been an LDT DUKW master for 18 months and held an MCA approved Tier 1 Level 2 Boatmasters' Licence.

When he joined LDT, the master undertook dedicated familiarisation training on DUKW handling and had since taken part in regular emergency drills, including fire and abandonment.

[22] Category C waters - tidal rivers, estuaries and large, deep lakes and lochs where the significant wave height could not be expected to exceed 1.2m at any time.

[23] Waterman - a river worker who transfers passengers across and along city rivers and estuaries in the United Kingdom.

[24] Lighterman - a crewman who loads and discharges cargoes on lighter barges.

2.6.2 Tour guide

The tour guide was British and was 27 years of age. He had worked for LDT for 4 months. Prior to working for LDT, he had some experience with watercraft and held military qualifications in this area. During his 4 months as a tour guide he had been given induction training on the DUKW operations and had participated in an emergency drill less than 3 weeks before the fire.

2.7 *CLEOPATRA*

2.7.1 General description

Cleopatra's external appearance and passenger compartment layout was similar to that of *WQ1*. However, as a result of the design modifications carried out by LDT, the London based APVs were significantly different to those operated in Liverpool.

Cleopatra had an 88kW Iveco Beta 120, 6-cylinder, naturally aspirated diesel engine and an Alison AT545 automatic gearbox. It was propelled through the water by a single, 4-bladed, clockwise rotating propeller, and had a single spade-type rudder.

The controls and instrumentation for both road and river transits were positioned in front of, and adjacent to, the master/driver's seat. The floor plates around the driver's seat had several open penetrations to accommodate the drivetrain gear levers and steering linkages.

Cleopatra was equipped with a very high frequency (VHF) digital selective calling (DSC) radio for communication with the PLA, LDT and other vessels. Navigation on the water was carried out visually. The vehicle was equipped with an automatic identification system (AIS), interfaced with a global positioning system (GPS), which allowed its position to be monitored remotely by the PLA, LDT and other AIS enabled craft. The vehicle was also fitted with a land based tracking system that allowed LDT staff to monitor its position on the road.

2.7.2 Hull

Cleopatra's basic hull layout was similar to that of the original DUKW and Liverpool APVs, but the minimum shell plate thickness of the LDT vehicles had been increased to 3mm. The shell plating in the propeller shaft tunnel had been strengthened following the lessons learned from the hull failure suffered by DUKW *Beatrice* in March 2001 **(Paragraph 1.16.2)**.

It was a statutory requirement for accommodation spaces on board Class V passenger vessels such as *Cleopatra*, to be separated from machinery spaces by gas-tight, insulated fire protection bulkheads. This requirement was highlighted in 1999 by Burness Corlett & Partners Ltd in its initial design submission. Due to perceived technical difficulties, the DUKW operators were exempted from the requirement on the understanding that the openings for the vehicles' drive shafts and control linkages would be kept to a minimum.

2.7.3 Propulsion drivetrain

A simplified illustration of *Cleopatra*'s propulsion drivetrain arrangements is shown in **Figure 38**. The output drive from the automatic gearbox was connected to the marine transfer box (MTB) by a sliding splined shaft via two Type 2030 universal joints (UJ) **(Figure 39)**. The main output shaft from the MTB was connected to the road transfer box. An articulated drive was taken from the road transfer box to drive the forward wheels while a further drive was taken aft, through a band-type hand brake assembly, to drive the after two sets of wheels. The forward wheels could be independently engaged and disengaged from the master's position to provide a four or six-wheel drive configuration.

The propeller shaft was brought into use just prior to entering the water by manually engaging the MTB from the master's control position. The propeller shaft was supported internally along its length by a plain journal bearing and a propeller thrust bearing.

The maximum engine speed while on the road was approximately 2200rpm. When the vehicle was in use on the river first gear was manually selected on the automatic gearbox and to achieve normal cruising speed the engine was set at approximately 1200rpm. The resultant speed of the output shaft to the MTB was approximately 650rpm with a propeller shaft speed of about 850rpm.

2.7.4 Rudder control

The LDT fleet had been fitted with electro-hydraulic steering gear. The rudder was controlled using a joystick located on the dashboard next to the steering wheel. It could also be controlled manually in an emergency from the back of the vehicle, using a handwheel. The emergency steering system had a 25-litre hydraulic oil header tank, which was positioned on the port aft end of the passenger compartment.

2.7.5 Brake system

The wheel brakes were air-assisted and were operated by depressing the foot pedal at the master's control position. The engine-driven air compressor charged three, 20-litre air reservoirs to approximately 10 bar. The reservoir cylinders were located under the passenger compartment deck behind the master's seat **(Figure 40)**. Flexible pipes connected the cylinders to the foot pedal operated distribution valve, and from there to the brakes.

2.7.6 Engine compartment

Cleopatra's engine compartment layout was last modified in 2012; this was to accommodate the vehicle's new Iveco Beta 120 engine and Alison automatic gearbox. The modifications included the enlargement of the drive shaft hole in the forward transverse bulkhead, the repositioning of the engine radiator and flow alterations for the engine and engine compartment cooling air system.

As with most road vehicles, *Cleopatra*'s engine was water cooled and its cooling water temperature was regulated by an air cooled radiator and thermostatic by-pass valve. Traditionally, the radiator is positioned at the front of a road vehicle and air is forced through it by the vehicle's forward motion. The DUKW radiator was encased

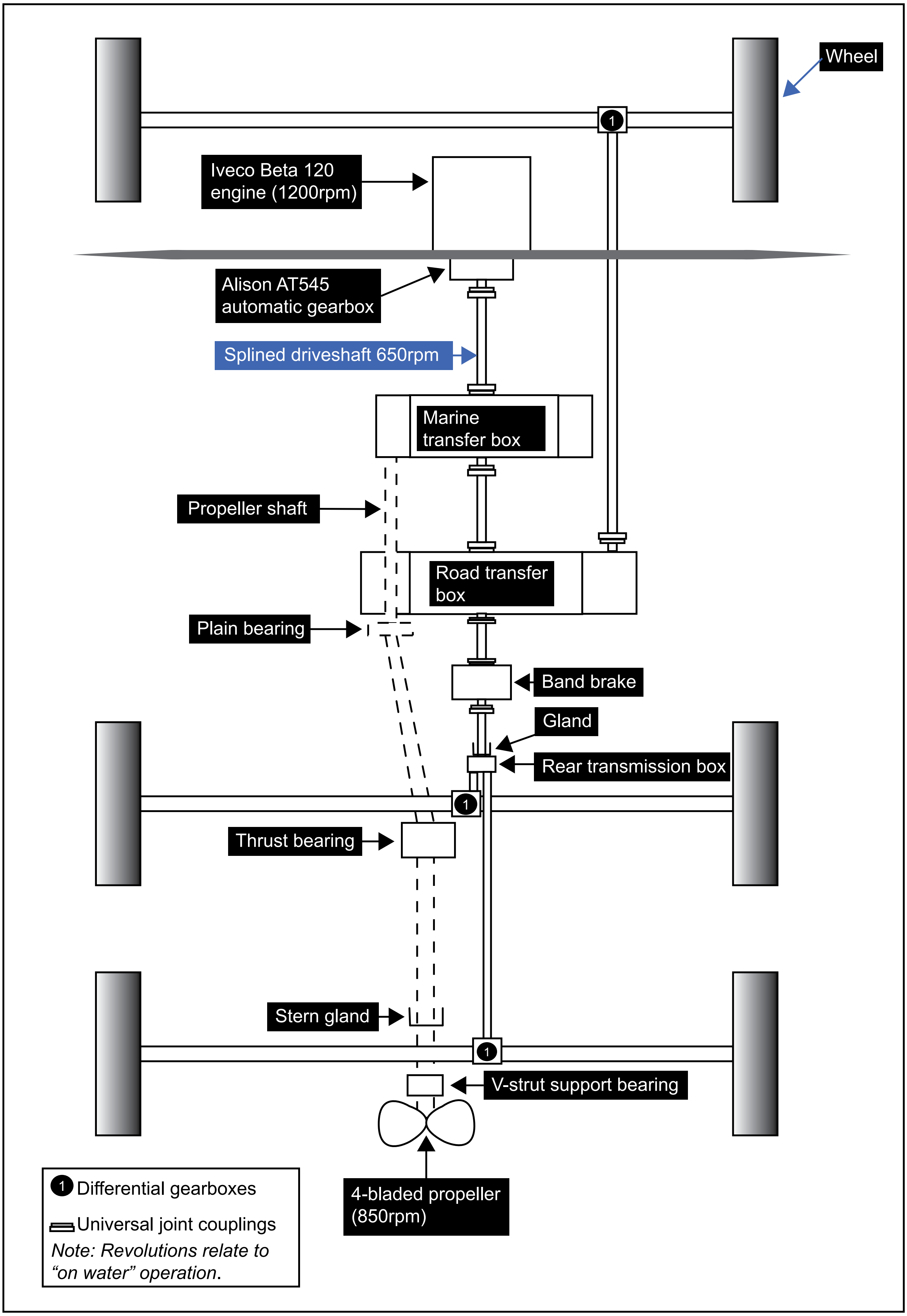


Figure 38: Simplified illustration of *Cleopatra*'s drivetrain

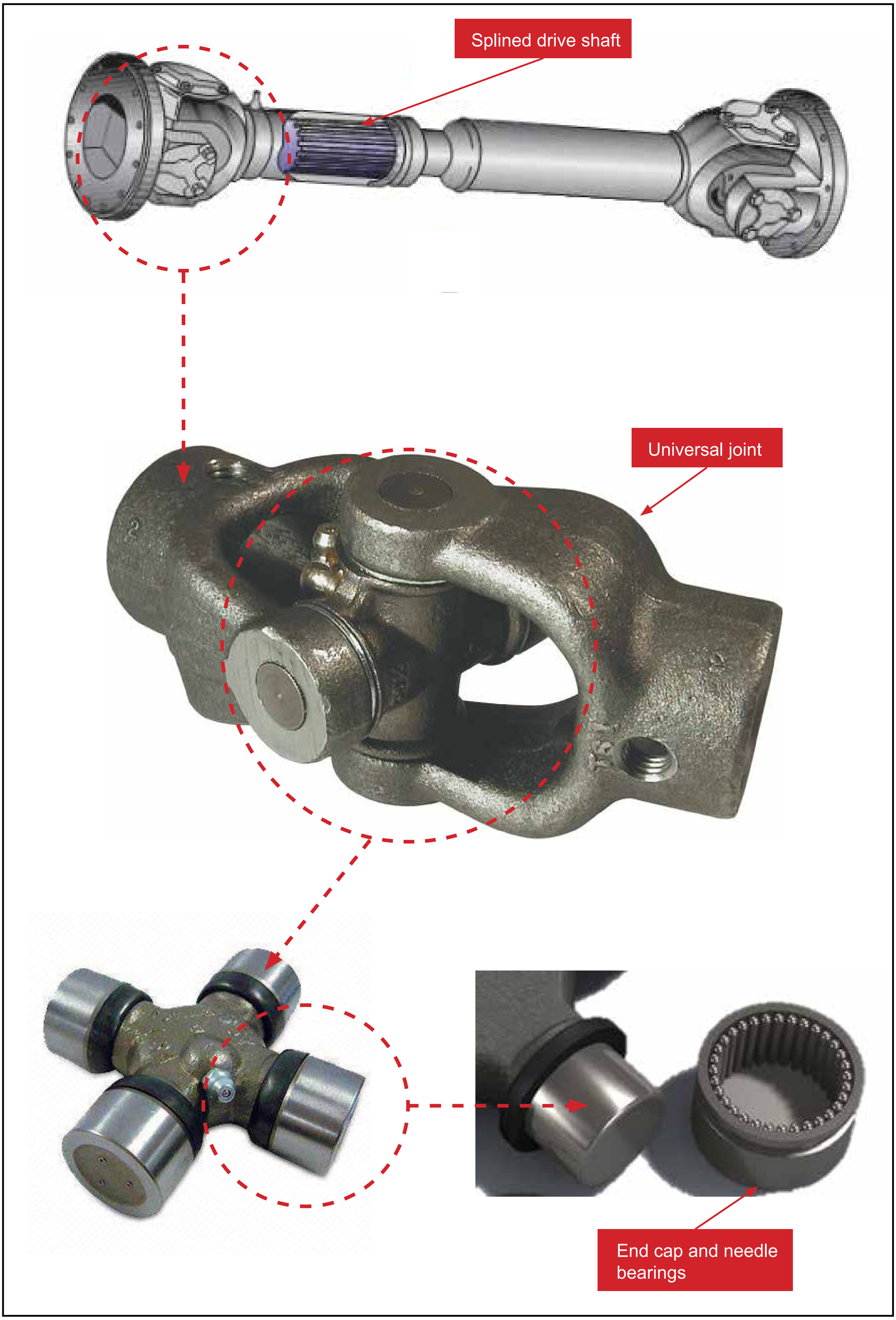


Figure 39: Typical sliding splined drive shaft and universal joint arrangement

Figure 40: Braking system air reservoirs

in a steel hull and the cooling air had to be forced through it by an engine-driven fan. The vehicle also had a keel water cooler, which was externally mounted under the bow to supplement the engine's air cooled radiator.

On the original DUKW, cold air was drawn into the engine compartment through an open deck grating in the cargo compartment behind the crew seats **(Figure 41)**. The cooling air passed under the driver's cab, across the engine compartment, and through the radiator into the bow compartment. The hot air then passed through the port and starboard cooling air passages and exhausted to atmosphere through the side ventilation grilles. In addition to cooling the water in the radiator, the cooling air also cooled the engine compartment. Earlier DUKW models had an auxiliary cooling air inlet flap fitted at the aft end of the engine compartment access hatch. This could be opened to provide extra cooling air in hot climates.

When the cargo compartment was converted into the passenger space the original main cooling air inlet grating was covered up and the engine compartment and bow compartment hatch covers were modified to accommodate aft facing cooling air supply and exhaust vents **(Figure 36)**. During their 13 years in operation, the cooling air flows on the LDT DUKWs had been altered several times. At the time of the accident, the original engine compartment cooling air passages had been removed from *Cleopatra*. The cooling air was drawn into the compartment through its aft hatch cover vent and, having passed through the radiator, exhausted to atmosphere through the forward (bow compartment) hatch cover vent.

In order to prevent the build-up of hot air at the after end of the engine compartment, electrically-driven extraction fans were fitted **(Figure 42)**. The hot air was drawn into the port and starboard ventilation void spaces and exhausted to atmosphere through the vehicle's original side vents.

The main engine exhaust pipe was routed down the starboard side of the engine compartment. It passed through the upper part of the starboard ventilation void space and terminated on the deck at the starboard forward corner of the crew cab. The section of the exhaust pipe within the engine compartment was lagged but the section that passed through the void space was not **(Figure 43)**.

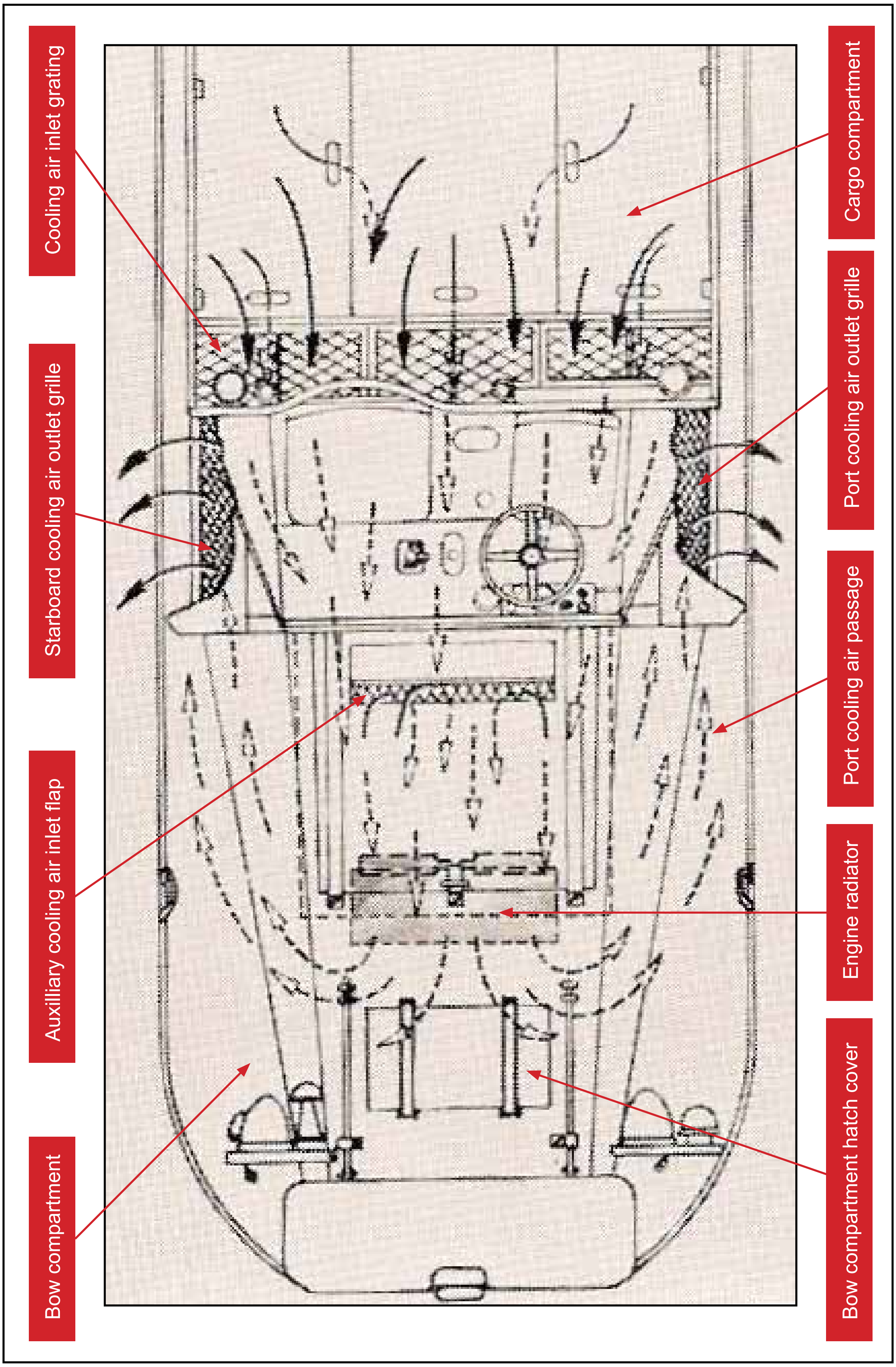


Figure 41: Original DUKW engine compartment cooling air system

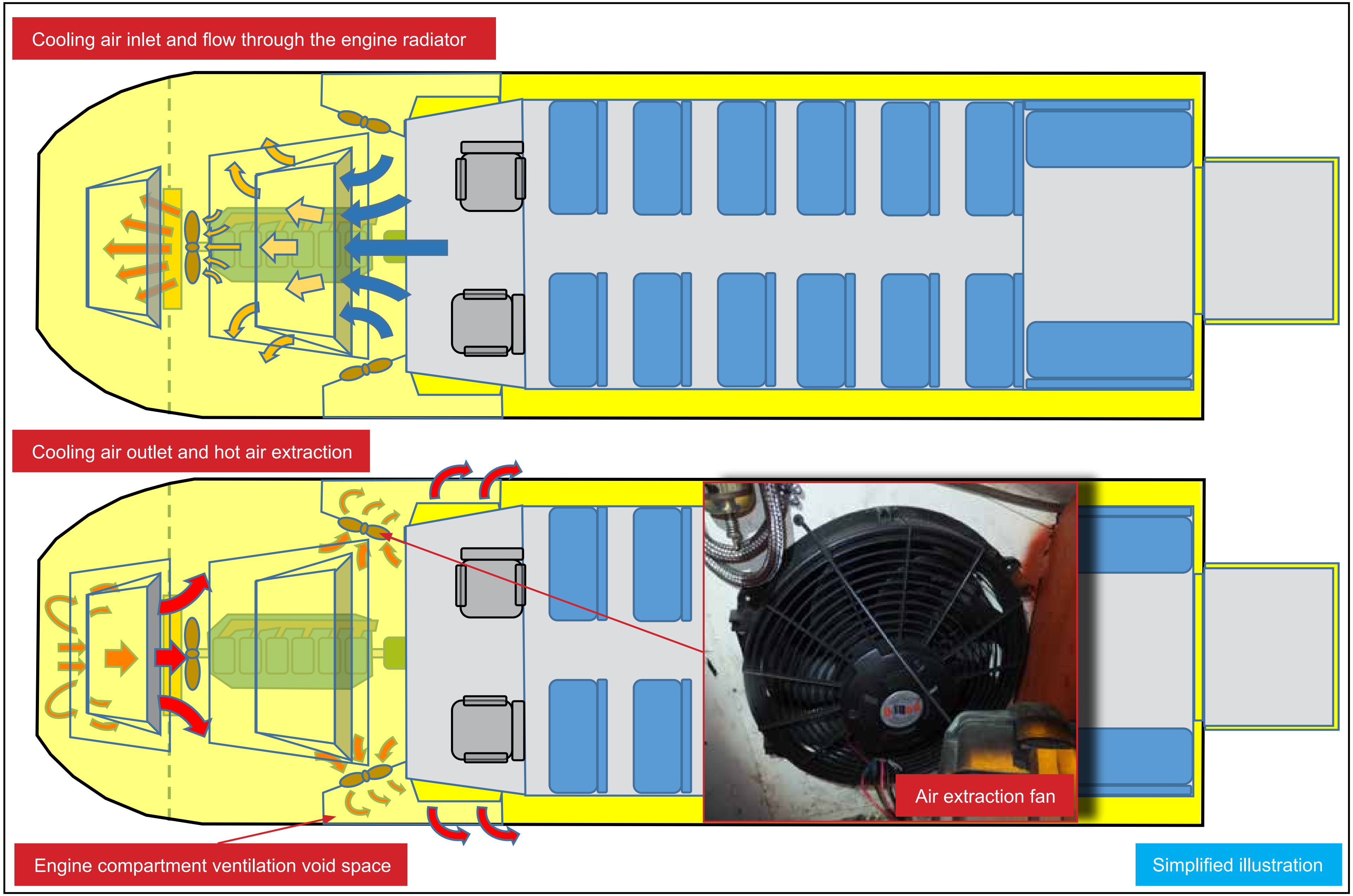


Figure 42: Modified engine cooling air flow and engine compartment hot air extraction

Figure 43: *Cleopatra*'s engine exhaust pipe

2.7.7 Engine compartment extraction fan controls

The extraction fans were configured for automatic start and manual-override control. The starboard extraction fan was wired to start automatically when the rudder's electro-hydraulic steering system was started in readiness for river operations. The port extraction fan was configured to start if the engine cooling water temperature reached 95ºC. The master could independently start the port extraction fan from his seated position if necessary. It is understood that the starboard fan was running and the port fan was stopped when the fire broke out.

2.7.8 Passenger compartment

Cleopatra's passenger and crew seating arrangements **(Figure 44)** were similar to those of *WQ1*. The side curtains were also similar in design and secured in the closed position by Velcro, but did not have the additional elasticated cords. The forward windscreen and side windows adjacent to the master's and tour guide's seats were toughened glass in line with PSV requirements. The steel floor plates under the crew seats were covered by a synthetic carpet.

Access and egress to the passenger compartment was by way of a boarding platform at the back of the vehicle and an aft watertight door. Unlike the Liverpool DUKWs, the boarding platform had two four stepped ladders, one on the left and one on the right hand side of the boarding platform. Each ladder could be raised or lowered by means of a rope, which was secured to a small set of cleats on the aft bulkhead **(Figure 45)**. During road journeys, one ladder was required to be left in the lowered position, whereas on the river both ladders were stowed in their raised position. Generally, for roadside embarkation and disembarkation, the vehicle was parked on the left side of the road and the left (port) ladder was used. To facilitate this, the door was secured at 90º to the aft bulwark **(Figure 45)**. The door could also be opened through 180º and secured flat against the bulwark to allow access and egress via the right side ladder.

Prior to the fire, the tour guide was seated facing the driver, with his legs in the companionway so that he could interact and maintain eye contact with passengers. The vehicle's side curtains were secured in the open position.

2.7.9 Engine fuel oil system

Cleopatra had a 160 litre fuel tank, which was located in the aft compartment under the starboard inboard facing passenger seat. The engine fuel supply and spill return lines were fitted to the top of the tank. Both lines ran forward, under the floor plating, down the starboard side of the vehicle. The spill line passed directly into the engine compartment while the supply line was routed under the crew cab dashboard to the port side of the vehicle before passing into the engine compartment. Under the dashboard, a flexible braided pipe had been used to connect the copper supply line to a ball-type emergency shut-off valve.

The engine-driven fuel lift pump drew the fuel through a combined water separator/ filter and a fine filter before delivering it to the fuel injection pump. The spill return line was directly connected to the fuel injection pump. When the engine was running, the fuel supply line between the fuel storage tank and the fuel lift pump inlet was under negative pressure; after the lift pump, the system was under positive pressure **(Figure 46)**.

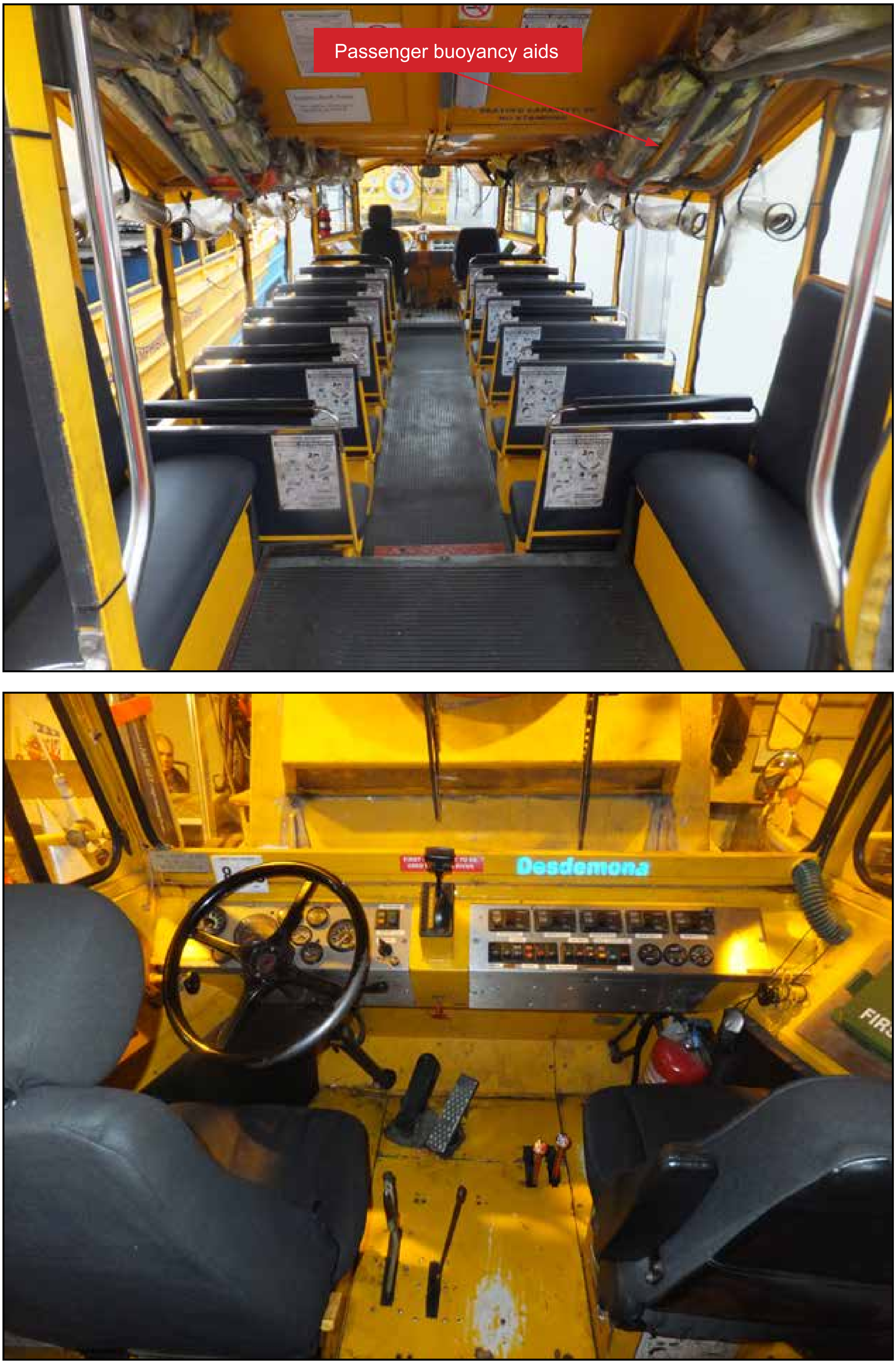


Figure 44: Typical London Duck Tours DUKW passenger compartment and crew cab layout

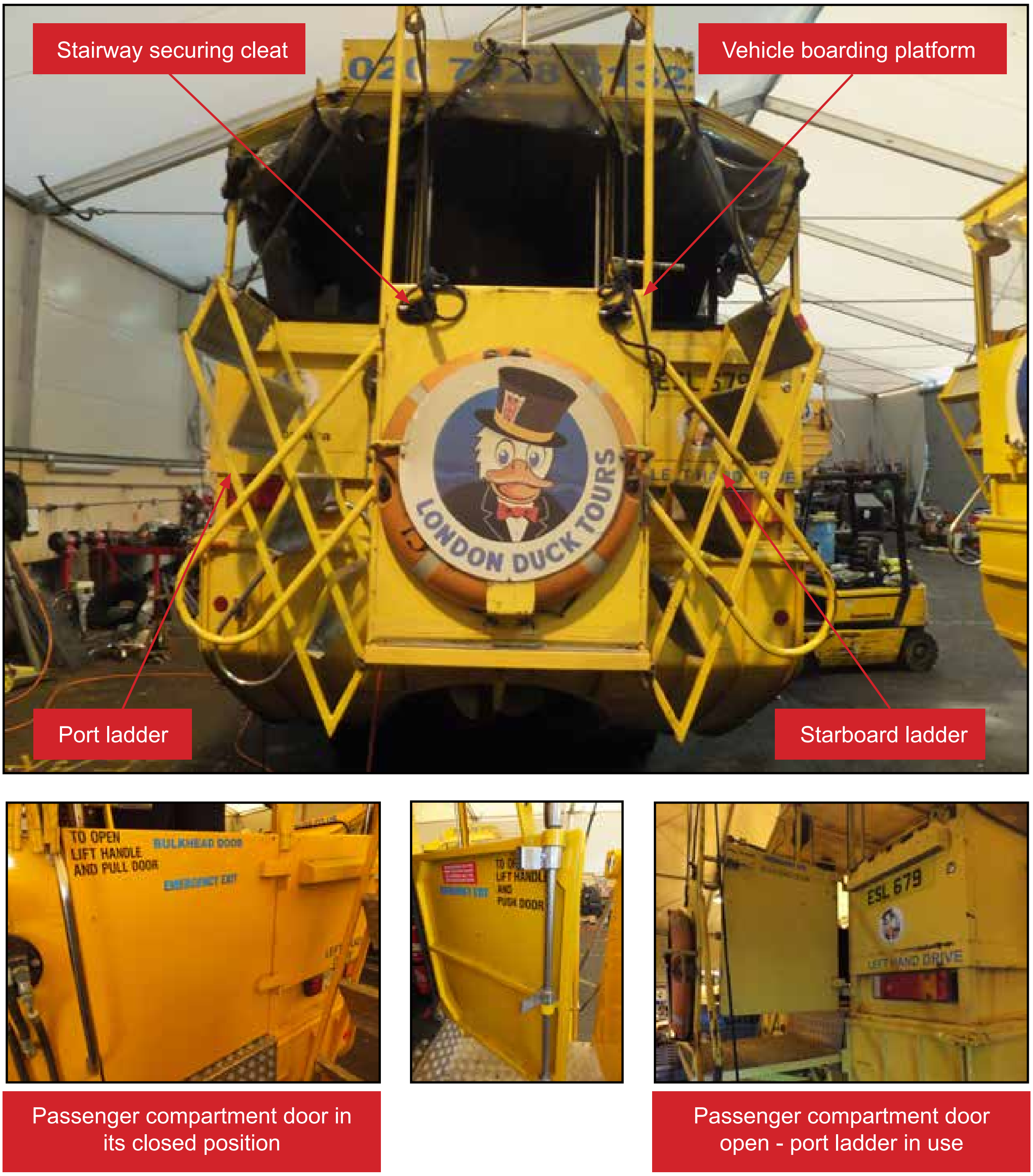


Figure 45: Boarding platform and ladders

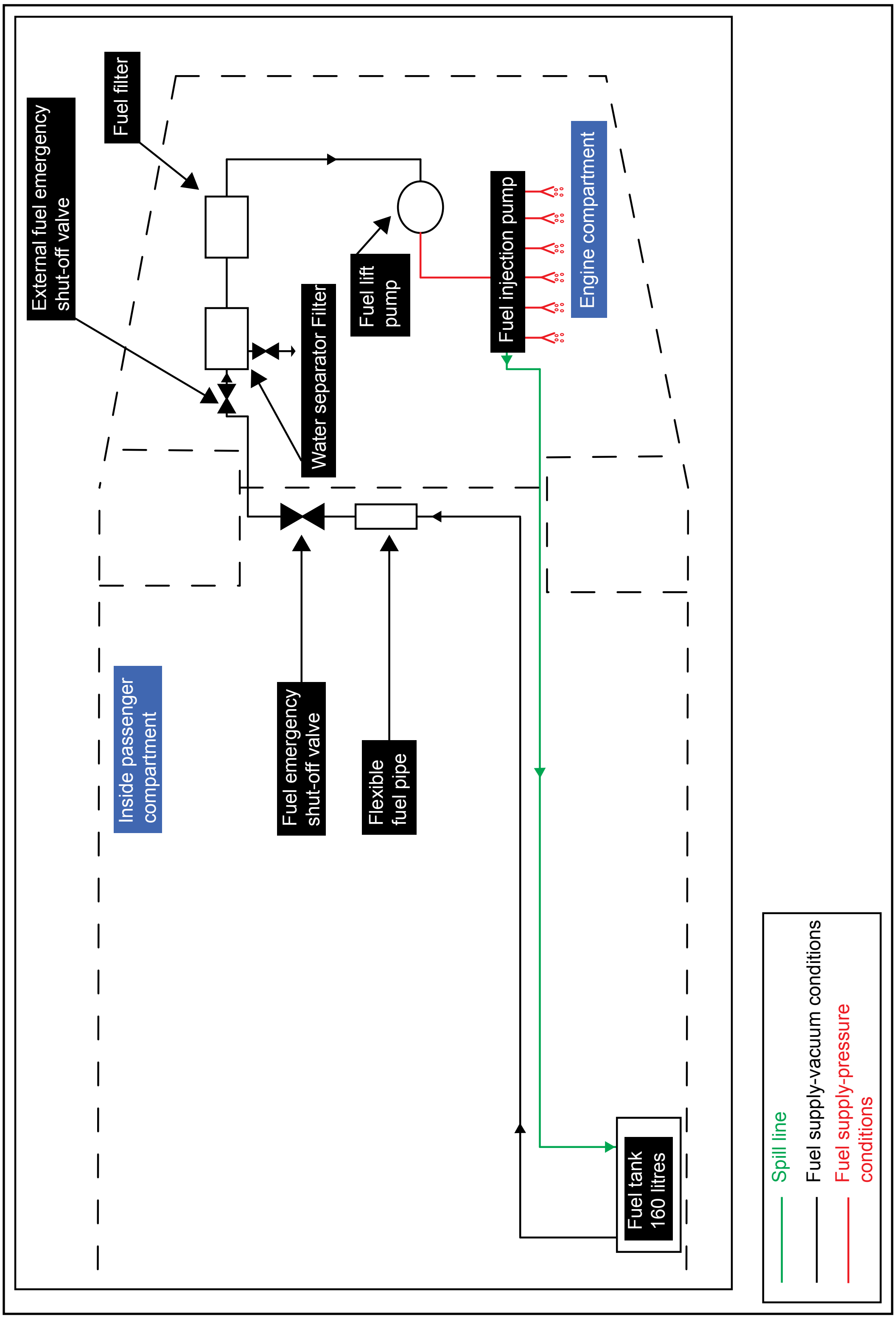


Figure 46: Simplified illustration of *Cleopatra*'s fuel supply system

2.7.10 Electrical distribution system

Cleopatra had two separate 24V electrical distribution systems: one for starting the engine and one to provide power to the vehicle's auxiliary systems. Each was supplied with power from two, 12V, 55 ampere-hour acid gel batteries connected in series. Each set of batteries was re-charged by the same engine-driven alternator, but the systems could not be cross-connected.

The engine starting batteries and main battery contactor were located in an enclosure under the front, port side passenger bench seat. In addition to engine starting, the system powered the dashboard instrumentation, lighting and the fuel supply valve solenoid through fused protected circuits.

The auxiliary batteries were located in an enclosure under the front, starboard side passenger bench seat. A manually-operated switch was fitted to isolate the batteries from the electrical distribution system and the batteries were protected from high circuit current conditions by a 100A fuse located in the battery enclosure. The battery power cables were routed under the passenger deck to ensure they were well away from sharp edges and were secured to the deck angled-support structure. The auxiliary services, which included the VHF radio, passenger announcement system, electro-hydraulic rudder controls, bilge pumps and lighting, were protected by appropriate capacity spade-type fuses.

2.8 FIRE-FIGHTING ARRANGEMENTS

2.8.1 Fire-fighting appliances

Cleopatra carried three 9 litre foam and one 2kg dry powder portable fire extinguishers. The foam extinguishers were stowed on the starboard side of the vehicle: one in front of the tour guide's seat, one behind it and one at the back of the passenger compartment close to the access door. The dry powder extinguisher was stowed on the port side behind the driver's seat.

The engine compartment had a fixed fire-extinguishing system, which comprised a 9 litre foam extinguisher connected to distribution pipework fitted with three discharge nozzles **(Figure 47)**. The system was activated by a manual-pull lever, which was located on the left hand side of the master's seat.

None of the portable fire extinguishers were used during the fire and the engine compartment's fixed fire-extinguishing system was not activated.

2.8.2 Engine compartment shut-down

In the case of an engine compartment fire, the fuel supply to the compartment could be isolated by closing one of the vehicle's two emergency fuel shut-off valves. One of the emergency shut-off valves was located under the crew cab dashboard and could be closed by the crew from their seated positions. The other was fitted outside the vehicle below the port side of the windscreen **(Figure 48)**.

The engine compartment cooling air inlet cowling and the port and starboard ventilation void space vents were fitted with remotely operated fire dampers. The fire dampers could be closed by the crew from their seated positions by pulling individual wire-pull handles **(Figure 48)**. The main cooling air outlet on top of the bow compartment hatch cover was not fitted with a fire damper and could not be closed in the event of fire. The Liverpool DUKWs had a similar cooling air inlet arrangement fitted to their engine compartment hatch covers but they did not have fire dampers.

Neither of the fuel shut-off valves were closed before the abandonment. The crew attempted to close the port and starboard ventilation void space fire dampers but they were unable to release the steel "R" clips that secured the wire pull handles because they were too hot. The master was unaware of the cooling air intake fire damper and therefore did not attempt to close it. During the post-accident inspections of the wire pull arrangements on other LDT vehicles, MAIB inspectors found that several of the R clips were difficult to remove under normal conditions.

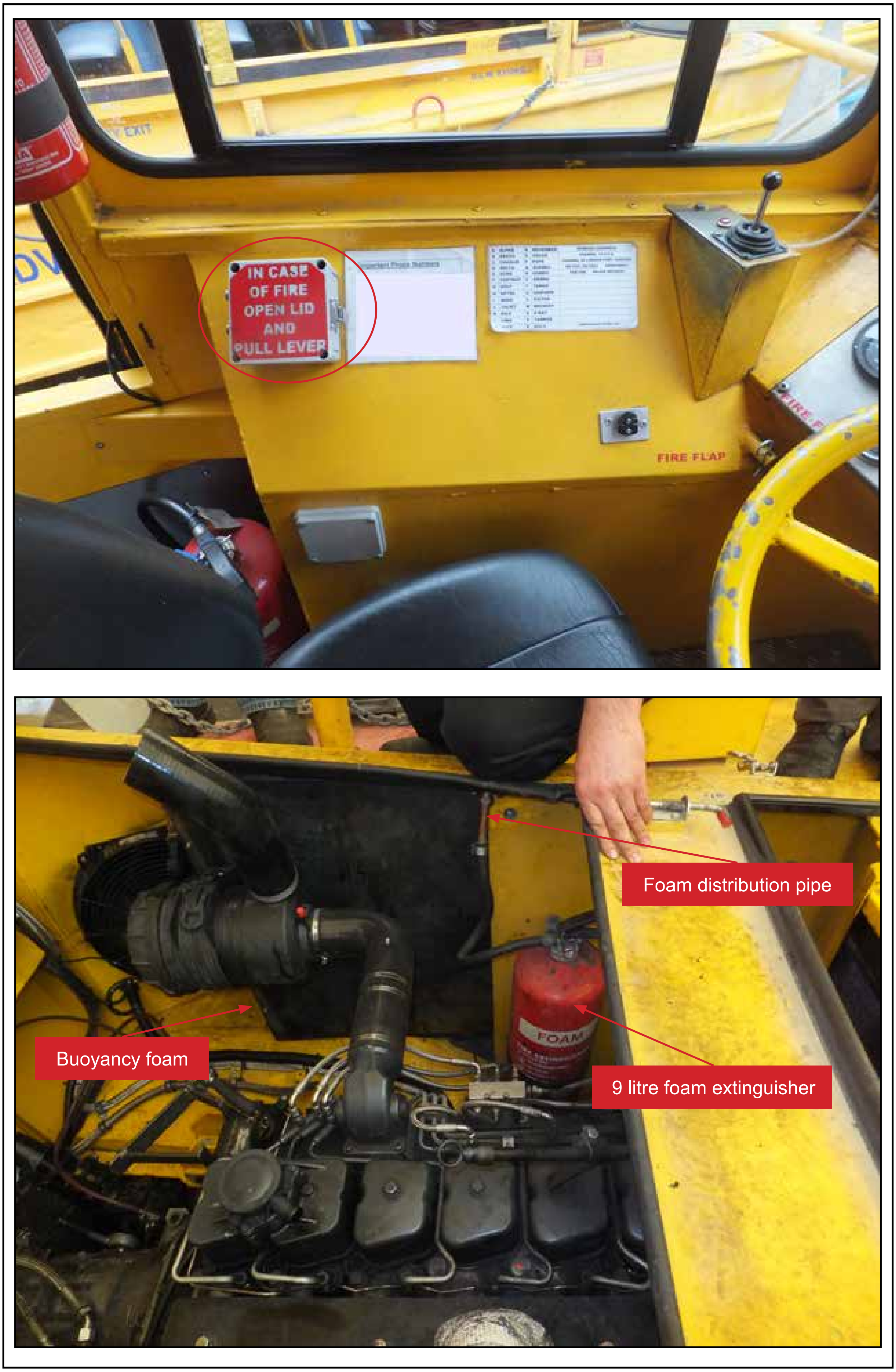


Figure 47: Typical London Duck Tours DUKW engine compartment fixed fire-fighting system

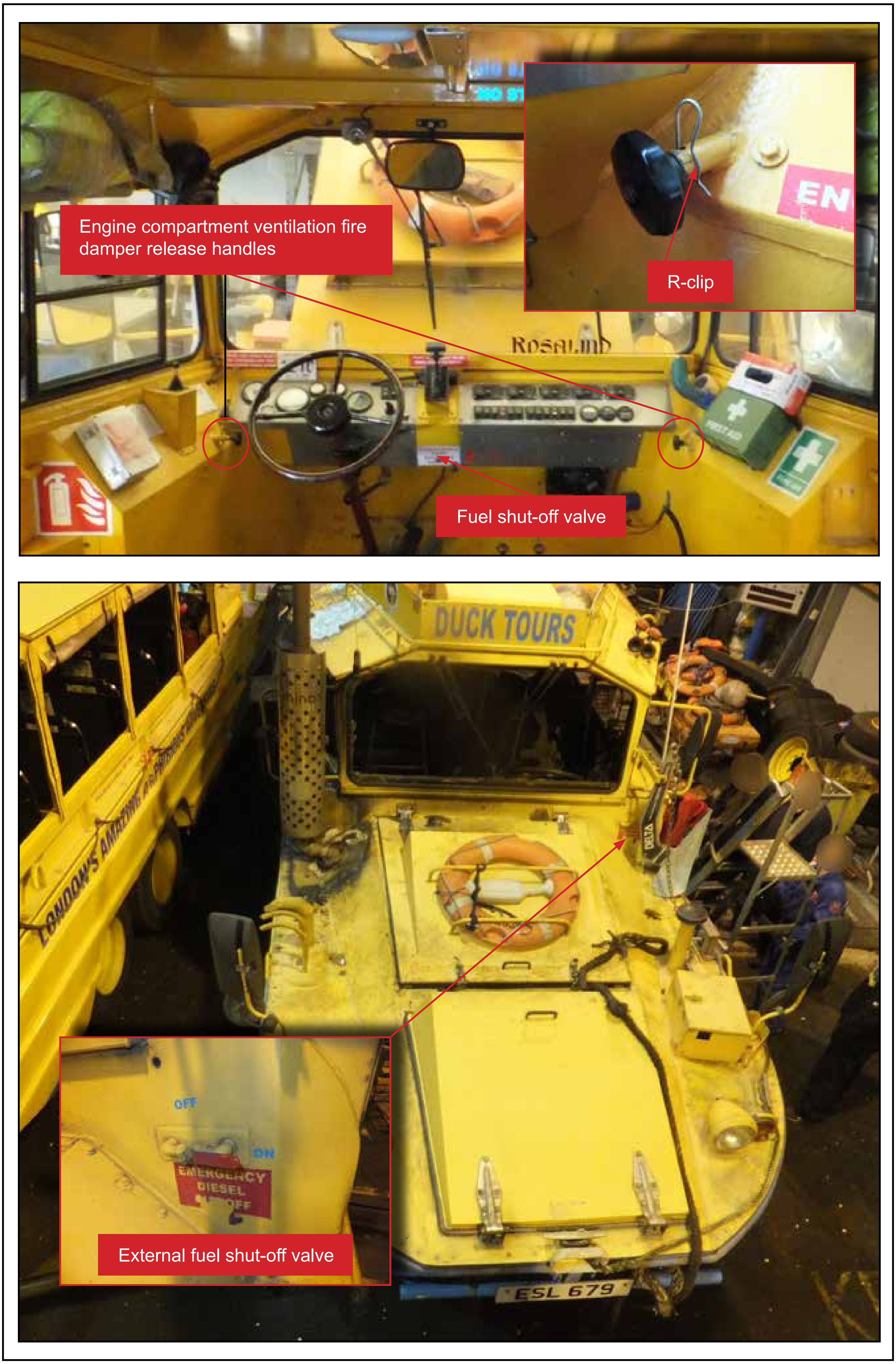


Figure 48: Emergency fuel shut-off valves and fire damper release handles in a similar vehicle

2.9 LIFE SAVING APPLIANCES

Cleopatra carried: 2 buoyant apparatus (1x20 person and 1x12 person), 4 lifebuoys, 30 adult buoyancy aids, 2 infant buoyancy aids, and 2 manually-activated gas-inflation lifejackets.

The buoyancy aids were provided for the passengers and the inflatable lifejackets were for the crew. The adult and infant buoyancy aids were of the solid foam type, they provided 100N and 50N of buoyancy respectively, and were stowed in racks above the passenger seats. The crew lifejackets provided 150N of buoyancy and were stowed close to their seats.

The buoyancy aids were stored in robust transparent plastic bags, many of which were tightly fitted and, according to the passenger feedback, were difficult to remove **(Figure 44)**. Prior to *Cleopatra* entering the river, passengers were given a buoyancy aid donning demonstration in accordance with the company's operating procedures. Donning instructions were also provided on the back of the passenger seats.

The majority of the passengers abandoned with buoyancy aids, however few had them secured properly and some simply held onto them. One 4 year old child abandoned without a buoyancy aid.

2.10 VESSEL SURVIVABILITY

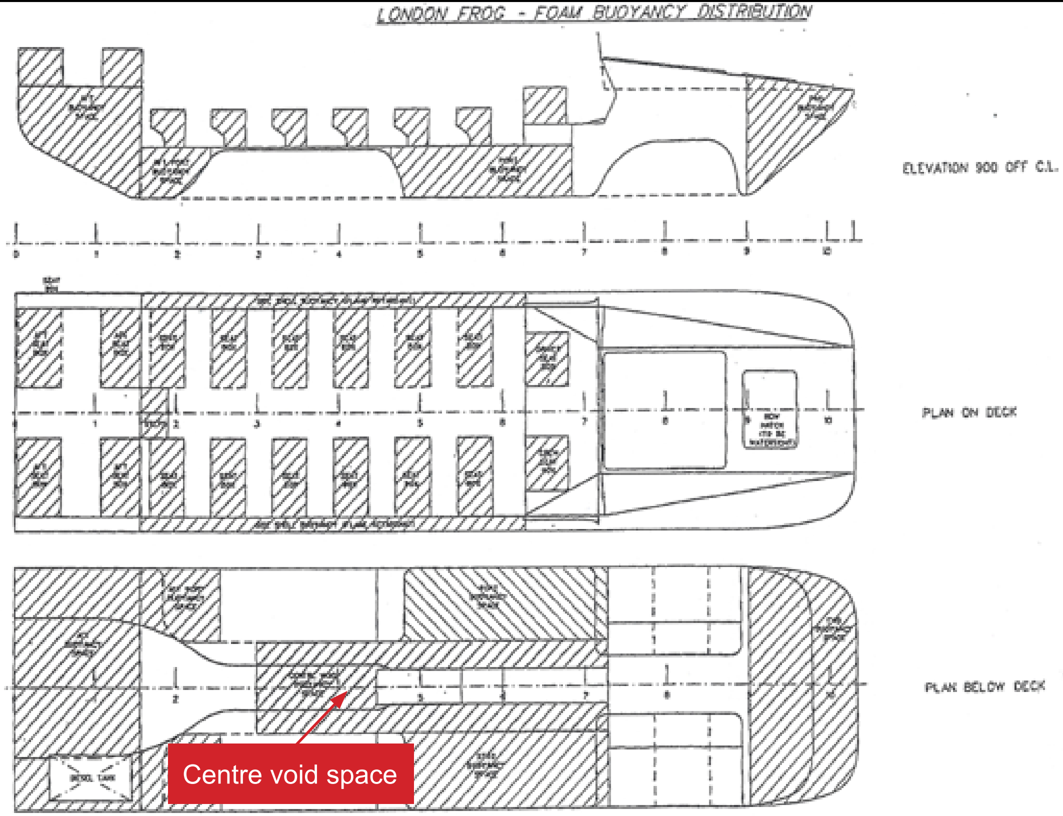
2.10.1 Buoyancy foam

The initial buoyancy calculations carried out by Burness Corlett & Partners Ltd in 1999 **(Paragraph 1.9)**, were based on several theoretical assumptions. The calculations were intended to provide an indication of how the converted DUKW could be configured to satisfy the damaged survivability requirements set out in MSN 1699(M). Other than those provisional calculations, LDT and the MCA were unable to provide any records relating to the original agreed volumes and distribution of buoyancy foam fitted within the hulls of the London based DUKWs.

In November 2008, the MCA raised concerns about progressive increases in the weight of the LDT DUKWs as a result of several structural modifications. In response, LDT instructed BCTQ to re-assess the buoyancy requirements for its vehicles. During the process, the MCA reminded LDT of the need to take account of the position of the vehicles' drive shafts and gearbox linkages when installing foam, and explained that the use of pre-formed blocks of foam would be preferable to the existing method of cutting and layering individual sheets of foam.

BCTQ used DUKW *Portia* to reassess the buoyancy foam requirements for the LDT fleet. Based on a vehicle weighbridge weight of 8.82t and a passenger and crew weight of 80kg per person, it was calculated that 12.22t of buoyancy was needed to provide the statutory 110% buoyancy for the vehicle in its fully laden condition. BCTQ estimated that the vehicle itself provided 3.17t of inherent buoyancy, and concluded that 9.05m^3 of buoyancy foam needed to be inserted.

Using the original results from Burness Corlett & Partners Ltd's computer model to help calculate the available space within the vehicle's hull, BCTQ identified 13 separate locations that it estimated, collectively, could hold 10m^3 of foam **(Figure 49)**. The BCTQ report re-emphasised the need to ensure that the foam in the central void space was securely fastened to prevent it making contact with the rotating drive shafts.



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Spaces for Buoyancy Foam

The following spaces have been identified as locations where buoyancy foam can be installed[3] - volumes are approximate

Location	Approx. Volume (m^3)	Approx. Buoyancy (T)
Aft Buoyancy Space	2.500	2.563
Port Buoyancy Space	1.013	1.038
Stbd Buoyancy Space	1.266	1.298
12 Seat Boxes (62x32.5x30 cm)	0.725	0.744
Aft Seat Box x 2 (32.5x90x30cm)	0.176	0.180
Aft Port Buoyancy Space	0.250	0.256
Aft Stbd Buoyancy Space	0.250	0.256
Centre Void Buoyancy Space	0.601	0.616
Side Shell	1.296	1.328
Fwd Buoyancy Space	1.580	1.620
Driver & Crew Seat Box	0.096	0.098
Step	0.030	0.031
Vent Spaces	0.220	0.226
Total	10.003	10.253

Table 2 – Spaces for Buoyancy Foam

Figure 49: BCTQ Ltd's 2008 buoyancy foam calculations

The MCA considered *Portia* to be representative of the LDT vehicles and accepted $9m^3$ as the standard volume of foam for the LDT fleet. According to weighbridge records, *Cleopatra* weighed 160kg less than *Portia* in 2009. In 2012, DUKW *Elizabeth*, with a weight of 9.16t, was the heaviest vehicle in the LDT fleet (340kg heavier than *Portia*).

2.10.2 Addition of buoyant foam following the sinking of *Wacker Quacker 1*

The MCA's decision in June 2013 to increase the London DUKWs' buoyancy foam requirement, from $9m^3$ to $10.6m^3$, was based on calculations carried out by its internal stability unit following the sinking of *WQ1*. The increased requirement meant that LDT had to identify new locations to install foam, and to fit increased volumes of foam, where possible, into the spaces previously designated in BCTQ's 2008 report. To ensure the maximum volume of foam was fitted in the hull spaces below the passenger compartment deck, LDT packed additional foam into the central void space above, below, and on both sides of its vehicles' rotating drive shafts and UJs **(Figure 50)**.

Once these spaces were full, the company packed foam into other spaces, such as the passenger compartment and the engine compartment's ventilation void spaces **(Figure 51)**. The foam in the cooling air void spaces was packed close to the unlagged engine exhaust, and gaps had been left to create channels to allow air from the engine compartment's extraction fans to flow out of the side vents. To prevent the foam moving within the ventilation void spaces, the garage mechanics glued the individual pieces of foam together.

The insertion of additional foam within the central void space, the engine compartment and its ventilation void spaces also increased the level of thermal and acoustic insulation surrounding the engine compartment. Prior to fitting the extra foam, it was not unusual for the passenger compartment to become overly warm, requiring the master to switch on the compartment's cooling fans. Following the fitting of the additional foam, it was noted that the passenger compartment was much cooler and the fans were seldom used.

2.10.3 Types of buoyancy foam

The buoyancy foam used on board *Cleopatra* was a mix of:

- single sheet and 3-ply laminate, closed cell, low-density, non-flame retardant Plastazote LD18 polyethylene foam; and
- single sheet high-density, closed cell, flame-retardant Microlen PE-30X FR polyethylene foam.

The low-density foam was packed into the passenger compartment bulkheads, around seating and under the passenger compartment floor plates in way of the propulsion drive shafts. The high-density foam was packed into the engine compartment and in its ventilation void spaces.

The low-density foam had a melting point of 107ºC and a flash point of >300ºC; the melting point of the high-density foam was unknown but its burning point[25] was estimated to be 430ºC.

[25] The Spanish manufacturer of the product confirmed that the term "burning point", referred to in the MSDS, is the same as "flash point".

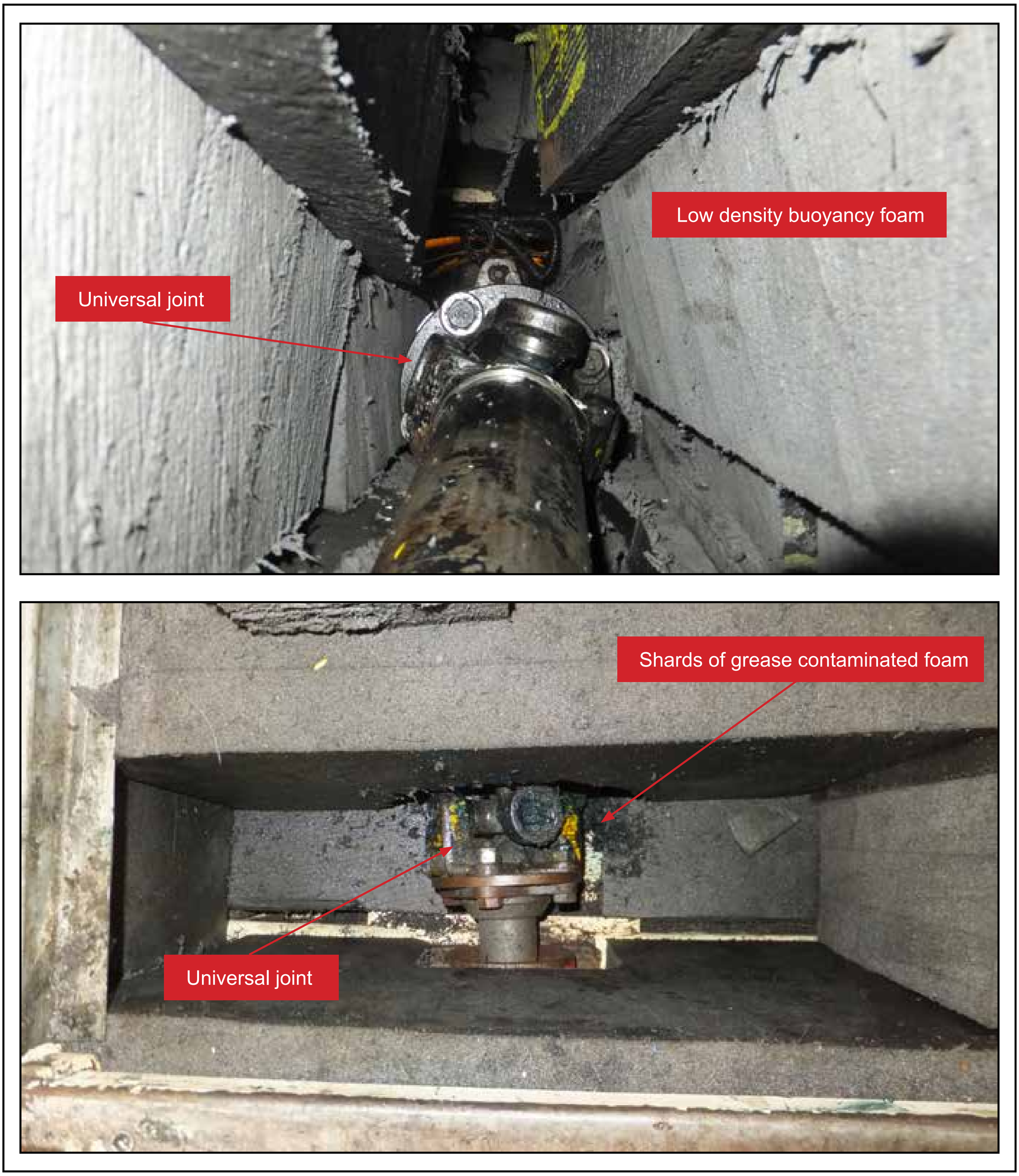

Figure 50: Buoyancy foam packed around the drivetrain in the centre void space of a London Duck Tours DUKW

Figure 51: Buoyancy foam packed into the engine compartment ventilation void spaces

2.11 FIRE INVESTIGATION

2.11.1 Overview

MAIB inspectors and members of LFB's Fire Investigation Team conducted a joint examination of *Cleopatra*, at LDT's fleet maintenance garage, during the period 29-30 September 2013.

A detailed visual examination was conducted of all areas of the vehicle. Initially, all external and normally accessible spaces and compartments were examined. On completion, the passenger compartment floor plates were lifted to expose the buoyancy foam, and allow access to the vehicle's drivetrain arrangements and auxiliary systems located in the void spaces below.

It was apparent from inside the passenger compartment that the fire damage was confined to the crew cab area and the front two rows of passenger seats. The buoyancy foam in the central void space was carefully removed, starting at the hand-operated band brake assembly and working forward. The foam under the crew cab and the front two rows of passenger seats, either side of the central void space, was also removed.

The initial findings indicated that the seat of the fire was located within the central void space, beneath the crew cab, immediately aft of the engine compartment's non-continuous transverse bulkhead. Detailed examination and external laboratory support was necessary to determine the probable source of ignition.

2.11.2 The external hull

The outer hull paintwork in the vicinity of the engine compartment's starboard ventilation void space, and in the area where the engine exhaust pipe exited onto the deck, had been partially consumed. Light smoke-damage was evident on top of both the engine and bow compartment access hatches but there was no evidence of paint blistering. The windscreen and the side windows adjacent to the tour guide's seat were missing but those adjacent to the master's position remained intact. The paint on the port side of the vehicle was unmarked by fire or smoke damage. The engine compartment air intake and the port and starboard ventilation void space fire dampers were in the fully open position.

2.11.3 Crew cab area and passenger compartment

The fire had totally consumed the master's and tour guide's seats, leaving only the steel framework, and had partially consumed the first two rows of the passenger seats and the carpeted floor covering in this area **(Figure 52)**. The dashboard was severely fire-damaged with the area in front of the tour guide's seat being the worst affected.

There was significant combustion debris and heat damage in the centre section of the crew cab floor plates. The damage in this area was far more severe than in any other area of the passenger compartment.

The buoyancy foam fitted to the hull, outboard of the starboard forward passenger seats had also been involved in the fire and had been partially consumed. There was also wide ranging heat damage to the port and starboard side curtains.

2.11.4 Engine compartment

The underside of the engine compartment access hatch had been fire damaged and was coated with soot, as was the compartment's aft transverse bulkhead. The engine's fuel filter/water-separator bowl had partially melted. The engine and automatic gearbox oil levels were checked and found to be at the correct running levels.

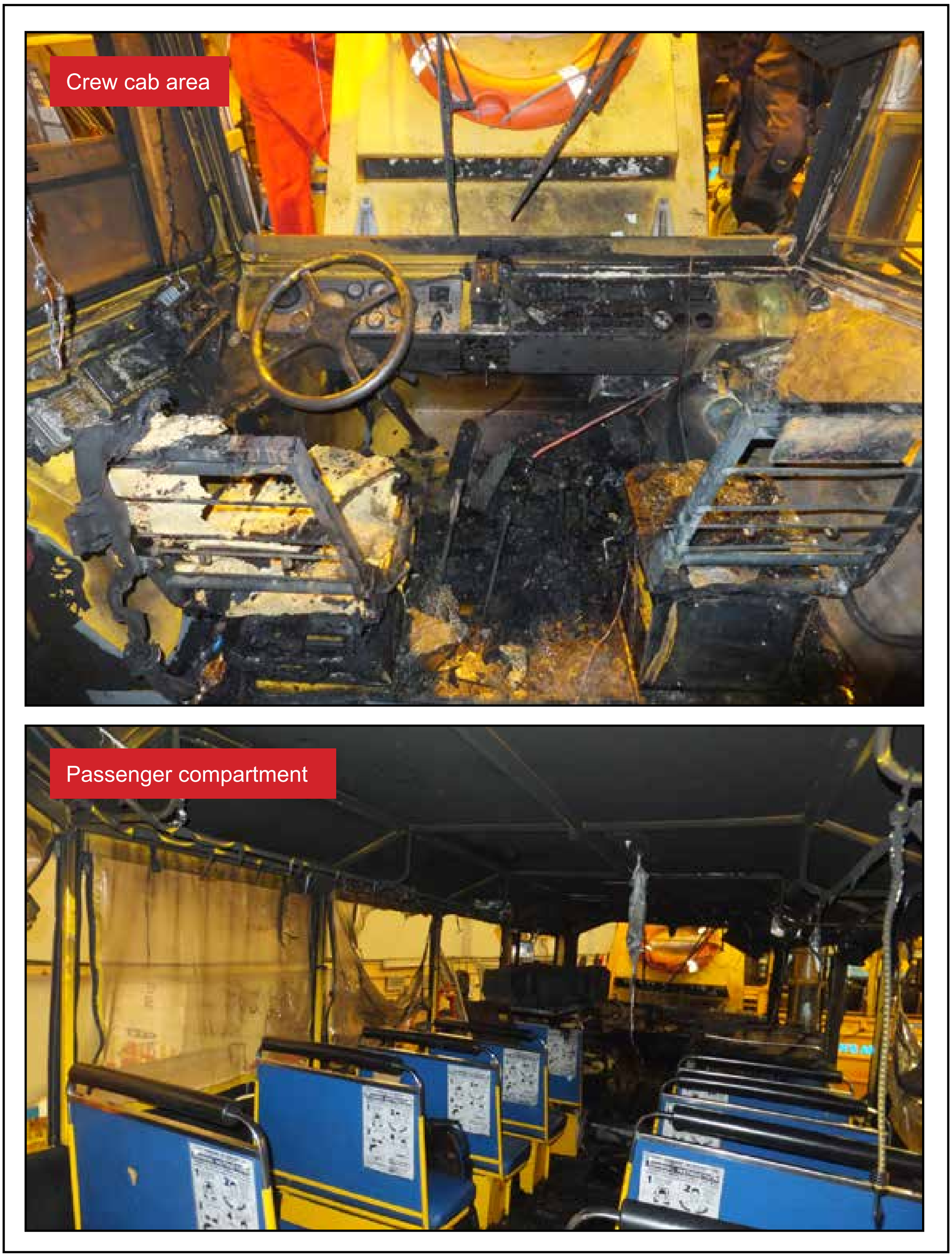

Figure 52: Fire damaged passenger compartment and crew cab

The starboard extraction fan had suffered extensive heat damage with most of its plastic grille consumed. The fan had fallen from its fastenings and was found on the wheel arch **(Figure 53)**. The port extraction fan remained intact but its plastic protective grille had suffered minor heat damage and was covered in soot deposits.

Figure 53: Fire damage within the engine compartment and starboard ventilation void space

2.11.5 Engine compartment cooling air ventilation void spaces

The starboard void space had suffered severe damage consistent with the images of the smoke and fire seen on CCTV and video footage evidence. The majority of the high-density flame-retardant buoyancy foam fitted in the area had been consumed. That remaining was extensively burnt **(Figure 53)**. There was no evidence that the fire had migrated into the port void space.

2.11.6 Central void space

Before the crew cab and passenger compartment deck plating was removed, the forward section of the central void space was examined from the engine compartment. It was apparent from viewing the area through the non-continuous transverse bulkhead that the area around the drive shaft connecting the automatic gearbox to the MTB had suffered considerable fire damage.

The internal hull coating under the plates was largely consumed, and that remaining was blistered. The non-flame-retardant, low-density foam, which had been fitted around the drive shaft, had been totally consumed by the fire **(Figure 54)** with most of the remaining exposed foam surfaces having melted. When the floor plates were removed from above the drive shaft it became evident that the damage was more pronounced on the starboard side of the shaft.

The surface of the splined drive shaft was covered in what appeared to be molten foam. The shaft was intact and still connected to the automatic gearbox and MTB by its UJs, and the shaft was able to be turned by hand. The drive shaft, complete with its two UJs, was removed for detailed analysis, the findings of which are detailed at **Paragraphs 2.12.1** and **2.12.2**.

Once the shaft had been removed, the area of deep seated burn was fully revealed. The site of deepest burn was found to be under the position of the forward UJ, which had been connected to the output flange of the automatic gearbox. A pit had formed in the foam in this area and the foam had been almost totally consumed **(Figure 55)**.

The oil levels in the marine and road transfer boxes were checked and found to be at their correct running levels.

2.11.7 Hydraulic steering system

Although the header tank for the electro-hydraulic steering system was located at the rear of the vehicle, its level was checked to determine the possibility of oil leakage feeding or contributing to the fire. The level was found to be normal.

2.11.8 Engine fuel oil system

A section of flexible hose, located under the dashboard, which had connected the fuel supply line to the internal emergency fuel shut-off valve, had been completely burnt through **(Figure 56)**. The line was above the level of the fuel tank and would not have been under pressure at the time of the fire. The flexible hose did not meet the MCA's minimum fire test standards.

The engine fuel supply and spill pipework was pressure tested to 70kPa; the test pressure was held successfully for 10 minutes. All connections from the fuel injection pump to the fuel injectors were checked and found to be tight and there was no evidence of fuel leakage. Both emergency fuel shut-off valves were found to be open.

Figure 54: Fire damage under the crew cab

Figure 55: Area of deepest burn within central void space aft of the automatic gearbox

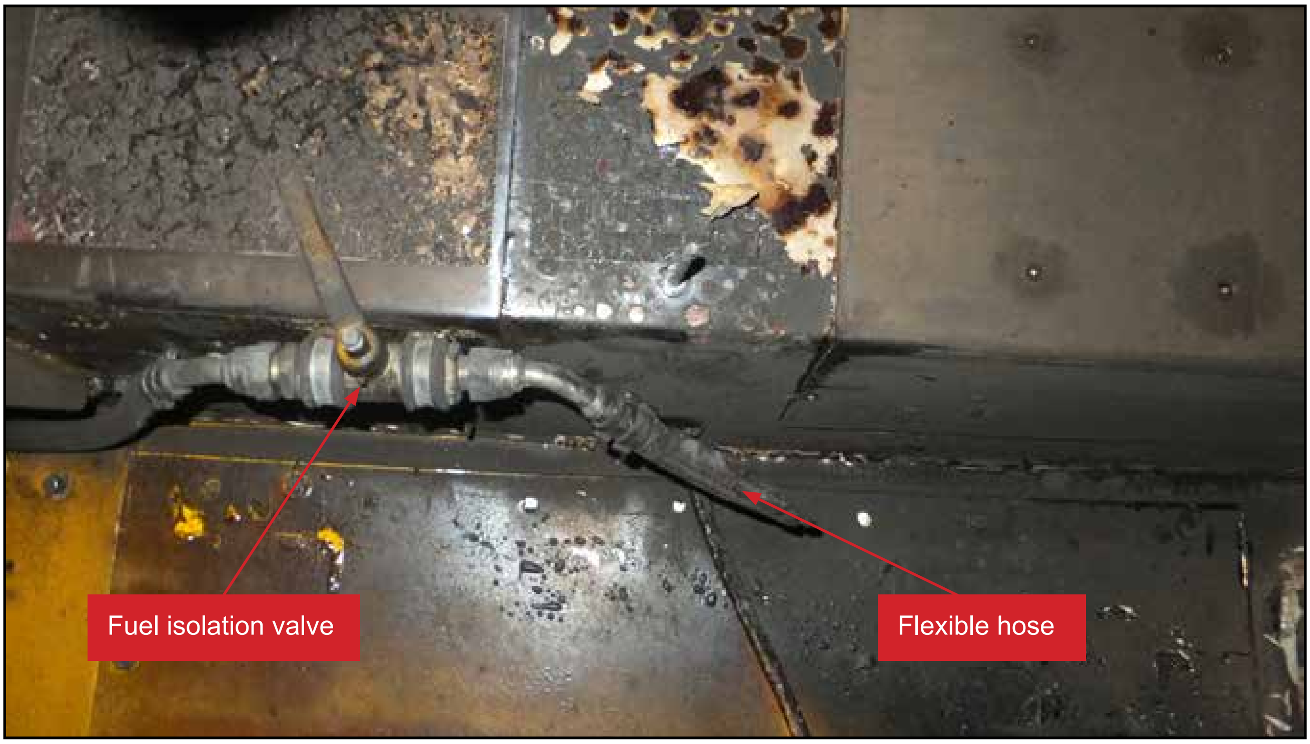

Figure 56: Burnt through section of flexible hose

2.11.9 Electrical distribution system

The auxiliary batteries had suffered light heat damage to their casings, cabling, plastic terminal covers, and securing straps. The protective 100A fuse was found to have ruptured but all connections were found to be tight. The insulation on the cables that ran under the floor plates close to the central void space had been consumed. There was significant damage to the wiring loom under the dashboard.

2.11.10 Hand-operated band brake

None of the low-density foam removed from above and around the band brake, or that under the output shaft from the road transfer box was fire damaged. The band brake showed no signs of fire damage or any evidence of overheating. Significant grease deposits were found on the removed foam and in the vicinity of the band brake connecting UJs **(Figure 57)**.

2.11.11 Brake system air reservoirs

The floor plates and foam covering the air brake reservoirs were removed. While there was no fire damage in this immediate area, the flexible pipes connected to the foot operated air distribution valve, adjacent to the foot pedal, had been consumed by the fire. There was no compressed air charge remaining in the reservoirs.

2.12 EXTERNAL FIRE INVESTIGATION SUPPORT

2.12.1 Bureau Veritas Fire Science Department fire investigation report

In order to determine the most likely source of ignition, the preliminary fire scene examination identified a need to:

- Determine the ignitability characteristics of samples of contaminated and non-contaminated low-density and high-density buoyancy foam.
- Conduct a visual examination of the splined drive shaft assembly and the UJs that had connected the automatic gearbox output shaft to the MTB.
- Establish if the engine compartment's starboard extraction fan was damaged by, or was a potential cause of the fire.

To achieve this, LFB contracted the London-based Bureau Veritas (BV) Fire Science Department to undertake a series of the laboratory tests and examinations.

The BV Fire Science Department report[26] found that:

- The edges of both the low and high-density foam could be easily ignited, especially those which had been contaminated with oil or grease.
- Once a flame was established it spread readily across the foam.
- Smaller sections of both foam types were significantly easier to ignite than their bulk surfaces.

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[26] *Fire Investigation – London Duck Tours, River Thames, near the Palace of Westminster - LFB/13-595 dated 9 December 2013.*

- The high-density flame-retardant foam produced much more, and denser, black smoke than the low-density non-flame-retardant type.
- The surface of the drive shaft and its UJs was covered in melted foam.
- There was no observable physical damage to the drive shaft assembly.
- The engine compartment's starboard extraction fan had no pre-existing electrical defects and was not causal to the fire.

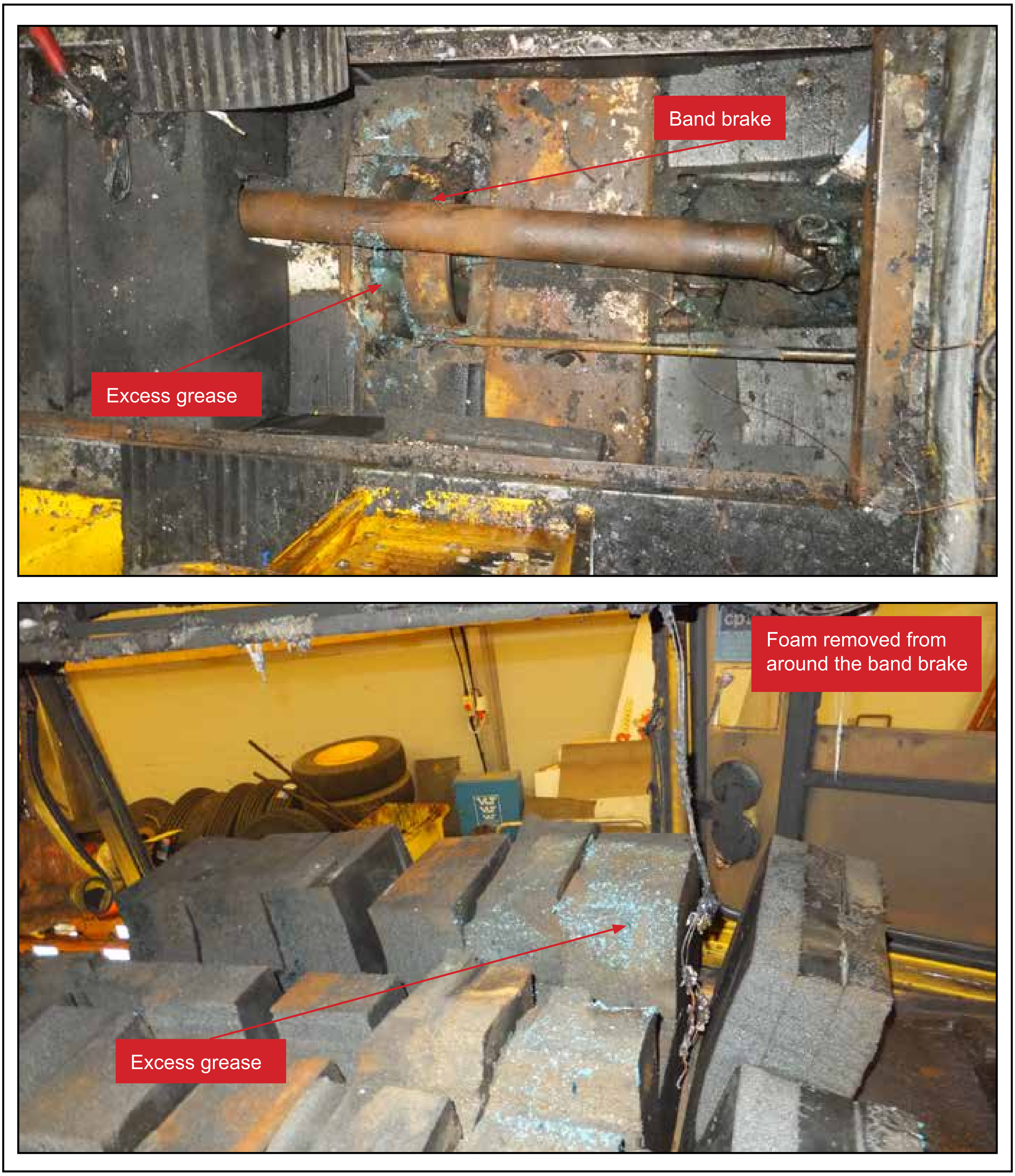

Figure 57: Grease contaminated foam removed from around the band brake

The laboratory report concluded that:

> *"There was no obvious ignition source in the vicinity of the buoyancy foam, and therefore the most likely cause of the fire was the action of the rotating drive shaft (or other moving parts) on the oil contaminated surfaces of the buoyancy foam blocks."*

2.12.2 Metallurgical analysis of *Cleopatra*'s drive shaft and UJs

Following BV's visual examination of the drive shaft assembly, the MAIB contracted Hampshire-based Materials Technology Limited (MTL) to conduct detailed metallurgical testing of the splined steel shaft and its UJs. MTL was tasked to:

- X-ray, dismantle and examine the drive shaft and both UJs for defects and signs of overheating.
- Examine the needle bearing rollers and contact surfaces for wear.
- Determine the type of grease used to lubricate the UJs.

The MTL laboratory report found that both UJs had suffered what appeared to be fretting corrosion indicative of misaligned in-service loading. It was evident from the extent of the wear on the surfaces of the UJ journal bearings that this would have been present prior to the fire. The excessive wear had caused circumferential cracking to one of the journal caps containing the needle bearing rollers **(Figure 58)**, and resulted in elevated temperatures of between 300-400°C, as confirmed by bluing of the needle bearing rollers.

Fourier transform infrared spectroscopy analysis was carried out on the samples of burnt grease on the external surfaces of the UJs and that contained within the bearing caps. The results had similar characteristics to the exemplar Castrol Heavy Duty Plus grease.

The MTL report concluded:

> *"… the overheated bearings, indicated by the evidence of bluing on the needle bearings, can be considered to be a possible cause of ignition where the environment is suitable and where flammable materials with the appropriate properties/characteristics are in contact or in close proximity…"*

2.13 SAFETY MANAGEMENT SYSTEM

In accordance with the requirements of the DSM Code, LDT had produced an Operational Procedures Manual and had identified its managing director as the company's DPA. The manual included dedicated sections for reacting to fire and instructions for abandonment. It also stated the requirement for crew training, including the need for emergency drills.

Section 16 of the Operational Procedures Manual described the actions to take when a fire was identified. The crew are instructed to:

1. *Check on the passengers and raise the alarm*.

2. *Put out a call on VHF channel 14*.

3. *Tackle the fire*.

4. *In the event of a fire in the engine bay, close the air vents and turn on the automatic emergency fire extinguisher*.

5. *Steer the craft to minimise the effect of the wind on the fire and warn other craft (a series of short blasts)*.

6. *IF THE FIRE IS A DANGER TO PASSENGERS AND CREW THEN PREPARE TO 'ABANDON SHIP'*.

Figure 58: Laboratory analysis of the forward drive shaft universal joint

Sections 17 and 20 of the manual describe the "Mayday" distress procedure and abandon ship procedures respectively. The guidance given in Section 17 stated that, *if in the opinion of the master it is an extreme and absolute emergency*, the crew should: tune the VHF radio to channel 16; wait for a gap in transmission; transmit a distress call. LDT's abandon ship procedure was:

1. *Make a 'MAYDAY' distress call on VHF channel 16*.

2. *Order all passengers and crew to don lifejackets*.

3. *Order second crew member to climb onto the upper deck (i.e. the roof of the passenger compartment) and pass down the buoyancy apparatus to the rear of the vessel. If time is of the essence then instruct that the three skull craft be thrown overboard*.

4. *Assemble passengers and ensure that less able passengers are paired up with more able passengers*.

5. *Disembark passengers and crew onto buoyant apparatus using the rear steps of the vessel if it is safe to do so*.

6. *If by opening the rear bulkhead door it would aggravate the position by increasing the volume of water being taken on board then instruct that the emergency exits are used.*

7. *If buoyant apparatus is full then assist remaining passengers into water*.

8. *Take a head count and keep a constant check of numbers*.

9. *Maintain watch for other vessels*.

10. *STAY CALM AND KEEP UP MORALE*.

2.14 VEHICLE MAINTENANCE

2.14.1 Maintenance management system

Similar to the TYD operation in Liverpool, the LDT vehicles were inspected, serviced and maintained in-house by the company's garage staff. The garage mechanics followed a maintenance management regime that was designed to comply with both MCA and VOSA requirements. Paper records were made of the planned and unplanned maintenance carried out on each vehicle.

2.14.2 Planned maintenance

Each morning, the company's engineers were required to ensure that all vehicles were road and river-worthy before allowing them to leave the garage. Before departure, the driver had to complete, sign and date a combined *vehicle and vessel* checklist.

As part of the weekly maintenance routines, the garage mechanics had to inspect and manually grease/lubricate the drivetrain bearings and UJs. They also checked the oil levels in the engine, automatic gearbox, transfer boxes and steering system. This was last carried out on *Cleopatra* on 23 September 2013, 6 days prior to the accident.

The vehicles' internal UJs were lubricated with Castrol Premium Heavy Duty Plus grease which had a flash point of 232°C. The external bearings and UJs were lubricated with Linton Lubricants' Protex Blue grease (flash point of >200°C).

To allow the garage mechanics to carry out their weekly maintenance tasks, they had to remove the tightly packed foam from each DUKW's central void space **(Figure 59)**. The need to remove and then reinstall the foam to grease the drive shaft bearings and UJs meant that the time taken to complete the vehicles' weekly maintenance routines increased significantly and required the vehicles to be taken out of service for a full day.

Figure 59: Tightly packed foam in central void space

When the greasing procedure was demonstrated using DUKW *Desdemona*, it was noted that the foam sections were difficult to remove and were in close proximity to the rotating shaft assemblies. Similar to *Cleopatra*, there was extensive evidence of grease contamination of the foam. It was also noted that the positions of each foam block or sheet had not been marked and force had to be applied to reinstate the foam. Once refitted it was not possible to identify if the foam was in contact with the rotating parts.

2.14.3 Unplanned breakdown repairs

The unplanned maintenance work was also recorded on the paper record sheets. Following the insertion of additional buoyancy foam, the garage staff experienced several related issues that required unplanned maintenance action.

During the inspection of the London DUKWs, it was observed that the foam filled spaces contained fine shards or “crumbs” of foam **(Figures 50** and **59)**. Most of the crumbs were created when the garage staff cut the individually sized blocks of foam in situ. It was also evident that “crumbs” had been created by the rubbing action between the blocks of tightly packed foam during the removal and refitting process, and as a result of contact between the foam and the rotating drivetrain. The foam crumbs had a tendency to build up in the bilges, and had occasionally blocked the bilge pump suctions.

2.15 SURVEYS AND INSPECTIONS

The LDT waterborne operation was overseen by the MCA’s Orpington Marine Office, and its surveyors applied a similar survey and inspection regime to those in Liverpool. Upon notification of an MCA survey or inspection, the garage staff prepared the vehicle(s) by removing foam, as necessary, from pre-selected locations. This enabled the surveyor to gain access to and inspect areas such as the hull and the drivetrain arrangements. On completion of survey, and typically following the surveyor’s departure, the foam was reinserted.

The most recent survey of *Cleopatra* took place on 3 October 2012. During the survey, it was identified that the vehicle was overdue a stability heel test, which was subsequently completed within the 4 months allotted by the surveyor. The total quantity and condition of buoyancy foam was not checked by the MCA at these surveys and inspections.

2.16 EMERGENCY RESPONSE

2.16.1 Thames RIB Experience

Thames RIB Experience was operating its three RIBs - *Ultimate*, *Experience* and *Adrenaline* - close by when the fire broke out. The skippers of the three RIBs heard *Cleopatra*’s request for assistance and immediately went to its aid. All of *Cleopatra*’s passengers and crew were rescued from the water before *Firedart* and the RNLI lifeboats arrived on scene.

2.16.2 Royal National lifeboat Institution

The nearest RNLI station to Westminster was at Tower Pier. The lifeboat from this station was unable to immediately assist as it was attending another incident. In view of this, the Chiswick lifeboat, which was several miles upstream was tasked.

Tower lifeboat hastily completed its earlier deployment mission and was on the scene of the fire at 1206. Chiswick lifeboat arrived at 1208. The lifeboats carried out a river search for possible casualties until it was confirmed that all *Cleopatra*'s occupants were safely on shore.

2.16.3 Police

At the time of the accident, the Marine Police Unit had one vessel, *MP2*, on duty. However, this was attending the same incident as the Tower Pier RNLI lifeboat. *MP2* initially became aware of the incident from overheard radio transmissions. This was later confirmed by the police's computer aided dispatch notification service from Lambeth police station. An airborne police helicopter was notified of the incident and diverted to the scene. The helicopter arrived on scene at 1200 and provided a live video link direct to the coastguard.

2.16.4 London Fire Brigade

In addition to conventional land based fire appliances, the LFB had two fireboats, one duty vessel and one reserve. These were stationed at Lambeth Fire Pontoon about 400m from the fire scene **(Figure 35)**.

The fireboat *Firedart* was notified of the incident by the coastguard. Around the same time, a member of the public misinformed the LFB control of a bus fire near the Houses of Parliament and a land based appliance was tasked to attend.

Firedart arrived on scene at 1159, quickly followed by the land based appliance tasked to the erroneous bus fire. After extinguishing the fire, *Firedart* towed *Cleopatra* away from the scene.

2.17 PASSENGER FEEDBACK

As part of the investigation and information gathering process, the MAIB posted questionnaires to the 28 passengers' declared addresses. Fourteen passengers (50%) responded by completed questionnaire or written narrative, while a further 6 (21%) communicated their thoughts by telephone to MAIB inspectors.

All of the responders stated that a safety brief and buoyancy aid donning demonstration had been given by the guide. They also commented on the light-hearted nature of the safety brief. However, 15% of the responders felt that the passengers did not give the brief the attention it deserved. Some of the passengers thought this was possibly due to the jocular nature of its delivery.

All the responders expressed concern about the buoyancy aids being stowed in strong polythene bags. Nineteen (70%) of the responders said, once they had removed the buoyancy aids from the bags, they had difficulty releasing the straps; 5 (19%) gave up and entered the water without them.

A mixed response was given to the crew's actions, with some responders thinking the crew did little to assist, whereas others highly praised their positive actions. Most commentators referred to the level of panic among the passengers following the fire, and recognised the difficulty the crew had trying to control such a situation.

2.18 SIMILAR ACCIDENTS

2.18.1 MAIB database

The MAIB's database contained records of 52 previously reported incidents involving LDT vehicles. Of those, 29 were attributed to mechanical and electrical faults, 2 resulting in fires and 3 requiring the passengers to be evacuated onto other vessels. The records also indicate that 9 of the mechanical failures were related to drivetrain issues with 2 of them specifying UJ failures. Three collisions and 6 groundings have also been reported.

Many of the accidents listed on the MAIB database were not reported to the MAIB by the company. According to MCA records, it was aware of an additional six incidents between 2010 and 2013 that had not been reported to the MAIB, which resulted in LDT DUKWs being towed off the river. Of those, four were the result of machinery breakdowns and one was a fouled propeller.

On 17 May 2013, the LFB fire boat *Fireflash* self-launched in response to a fire on board DUKW *Desdemona*. At the time, *Desdemona* was ashore at the Lacks Dock slipway and the fire had been extinguished by the time the fire crew arrived. The incident was not reported to the MAIB, but overheating of the vehicle's hand brake was understood to be the cause.

2.18.2 *Elizabeth*

On 12 July 2013 LDT's DUKW *Elizabeth* was towed from the River Thames following the failure of one the UJs connecting the automatic gearbox output to the MTB. According to LDT's maintenance records, this was an uncommon occurrence. *Elizabeth* was not in service at the time of the accident, it had recently been packed with additional foam and was being used to deliver crew training prior to being put back into service. The incident was reported to the MAIB by the PLA and, following a request for more information, LDT advised the MAIB that its internal investigation had identified that temperatures within the engine compartment and surrounding areas had increased following its ventilation modifications and the insertion of additional buoyancy foam. As a result, it was considered likely that the UJ had overheated and run dry of lubricant.

It was the DPA's understanding that, as a result of this incident, newly sourced high-temperature resistant grease was being used across the DUKW fleet to lubricate the UJs. However, this investigation has identified that the replacement high-temperature grease had the same properties as that previously used.

2.18.3 *Mistress Quickly*

At 1125 on 5 June 2008, LDT DUKW *Mistress Quickly* suffered a mechanical breakdown on the River Thames. Initially, a knocking noise was heard coming from the engine compartment, a few minutes later the engine seized. The master immediately reported the incident to the Thames VTS and dropped anchor. This was observed by the crew of an LFB fire tender, and it was subsequently manoeuvred alongside to provide assistance.

Mistress Quickly's master observed smoke and sparks coming from the engine compartment vents and immediately isolated the fuel supply line and closed the inlet vent fire damper. The nine passengers and two crew then evacuated onto the fire tender. The LFB crew climbed on board the DUKW and operated its fixed fire extinguishing system. When they opened the engine compartment hatch the fire was still burning, so the firefighters extinguished it using their own portable extinguishers.

Following the incident, the Chief Inspector of Marine Accidents wrote to LDT instructing it to ensure that masters of its vessels are fully acquainted with, and regularly exercised in the emergency procedures contained within the company's operational procedures manual.

2.18.4 World War 2

DUKWs have always had engine and engine compartment cooling issues, particularly in hot climates. The US army's *The DUKW, Its Operation and Uses* manual warned against the dangers of restricting the cooling air flow to and from the engine compartment. The manual specifically warned against putting anything in the forward compartment or within the air passages, pointing out that *the heat of the engine cooling air plus the heat of the exhaust piping is almost certain to start a fire*.

SECTION 3 - ANALYSIS

3.1 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.

3.2 OVERVIEW

The causes and circumstances of *WQ1*'s hull failure and subsequent sinking, and the fire on board *Cleopatra* will be considered in this section. The underlying contributory factors associated with these adverse outcomes will be discussed and the vehicle abandonments and emergency responses will be analysed.

The body of evidence to support the analysis was comprehensive and included video and CCTV footage, witness accounts, scientific analysis of physical evidence, practical trials and reconstructions, and documented records. The MAIB also received a high level of co-operation and expert input from a number of other APV operators and designers from within the UK and abroad.

3.3 THE SINKING OF *WACKER QUACKER 1*

3.3.1 Overview

WQ1 sank suddenly by the bow in Salthouse Dock, Liverpool, because:

- It suffered massive flooding through two large holes in its outer hull plating below the waterline, and the vehicle's electric powered bilge pumps did not have the pumping capacity needed to cope with the rate of water ingress.

- Once fully flooded, *WQ1* did not have sufficient residual buoyancy to remain afloat.

The holes in *WQ1*'s hull were created as a result of the forces generated when its propeller became fouled by an old discarded car tyre. *WQ1*'s 31 passengers and 2 crew abandoned the vehicle and either swam ashore or were rescued. No one was killed or seriously injured.

3.3.2 The hull failure

When *WQ1*'s propeller picked up the car tyre, the resultant forces were transferred to the vehicle's hull through its propeller shaft v-strut. The structural strength of the hull was not sufficient to absorb the forces generated, allowing the v-strut feet to be ripped from their mountings. This created two large holes below the waterline in the propeller tunnel plating.

The v-strut was designed to support the propeller shaft and transfer the transverse forces acting on the propeller to the vehicle's hull. The internal v-strut support shoes were designed to spread the load and transfer dynamic forces acting on the v-strut to the vehicle's aft transverse bulkhead. However, the welds that fastened the internal shoes to the aft transverse bulkhead stiffeners had corroded away, as had the welds between the base of the bulkhead and the outer shell plating **(Figure 60)**.

Figure 60: Hull corrosion within *Wacker Quacker 1*'s aft void space

This meant that the full weight of the forces acting on the hull through the v-strut was being taken entirely by the shell plating. The propeller tunnel plating itself had suffered severe corrosion wastage and therefore had been significantly weakened.

Regardless of *WQ1*'s material condition, the DUKW's hull plating was never designed to absorb such forces. This point was identified by the US army's recommendation to fit propeller guards **(Paragraph 1.16.5)** and reinforced when the propeller of DUKW *Beatrice* was fouled on the River Thames in 2001 **(Paragraph 1.16.2)**. Had TYD learned lessons from previous accidents, or acted on the advice of LDT after the sinking of *WQ4*, and reinforced the propeller tunnel plating, it is possible that the fouling of the propeller would not have resulted in the rupturing of the vehicle's hull.

3.3.3 The fouling of the propeller

WQ1's propeller drive shaft seized shortly after the vehicle had rolled back into the water following the driver's aborted attempt to climb out of Salthouse Dock. The police divers found several discarded car tyres and other items of debris on the dock bed at the bottom of the concrete slipway and close to the sunken vehicle.

It is likely that the tyre was disturbed from the dock bed by *WQ1*'s wheels as it rolled back down the slipway, and was picked up by the propeller as the driver tried to manoeuvre the vehicle astern.

Propeller fouling was a foreseeable hazard that would have been identified had the risks to TYD's waterborne operations been systematically assessed. The likelihood of the hazard being realised would have been significantly reduced if steps had been taken to periodically inspect and clear debris from the bottom of the slipways. The fitting of a propeller guard might also have reduced the likelihood of the tyre fouling the propeller.

3.3.4 Material condition of *Wacker Quacker 1* and The Yellow Duckmarine fleet

Following its sinking, *WQ1* was closely examined by MAIB inspectors and MCA surveyors and was found to be in an extremely poor material condition. Internally its hull was heavily corroded **(Figure 60)**; large sections of its electrical cabling was found to be hanging loose, and were unprotected; and much of its instrumentation did not work. Externally its hull was covered in a patchwork of welded repairs (doublers) that had not been approved by the regulator and did not meet basic maritime standards. It was also evident from the company's maintenance records that *WQ1*'s steering system and drivetrain arrangements were unreliable and prone to failure.

The other vehicles in the Liverpool fleet were in a similar condition to *WQ1*. It was apparent that the garage staff had worked long hours to keep the TYD vehicles in service. However, it was also clear that they were under-resourced and *WQ1*, and the rest of the Liverpool fleet, had been allowed to deteriorate to an unsafe condition over a prolonged period of time.

Operating in sea water exposed the hulls of TYD's vehicles to a high risk of corrosion and their thin shell plating made them particularly susceptible to corrosion related hull failure. Although the fouling of *WQ1*'s propeller triggered the hull failure in this instance, the hull was close to failing under normal operating conditions, as was the case with *WQ2* only 2 weeks earlier **(Paragraph 1.16.1)**. *WQ1* had been poorly maintained, and it should not have been operating on the water.

3.3.5 Maintenance management

TYD's paper-based maintenance management system was designed to satisfy the requirements of both the maritime and the land-based regulators. It allowed the company's garage mechanics to record their scheduled inspections, planned maintenance routines and defect repairs on daily, weekly and monthly record sheets.

The records showed that the DUKW masters often reported excessive levels of flooding and that the mechanics frequently discovered and repaired holes in the vehicles' hulls. The types of hull failures the garage staff were discovering should have been reported to the MCA and the MAIB. The hull repairs should have met recognised maritime standards and should have been overseen or approved by the regulator.

The maintenance management system successfully captured the day to day issues the garage staff had to deal with. The number of machinery breakdowns, hull failures and flooding incidents in the months leading up to the sinking of *WQ1* was remarkably high. The sinking of *WQ4* and the warnings issued by the MCA following its most recent incognito inspection, meant the company was fully aware of the waterborne risks it was required to manage. Despite this, TYD demonstrated that it was prepared to take passengers onto the water in severely sub-standard vehicles.

3.4 THE FIRE ON BOARD *CLEOPATRA*

3.4.1 Overview

Cleopatra suffered a major fire during the waterborne section of an amphibious sightseeing tour. The fire quickly spread to the passenger compartment, engulfing its 28 passengers and 2 crew in thick black smoke. This led to the rapid abandonment of the vehicle into the River Thames. No one was killed or seriously injured.

3.4.2 Seat of the fire

The examination of the fire damaged vehicle and burn patterns indicated that the seat of the fire was located in the central void space, below the crew cab, immediately aft of the engine compartment transverse bulkhead **(Figure 55)**. This assessment was supported by witness accounts.

Smoke was first seen coming from the cooling air inlet on top of the engine compartment hatch, quickly followed by smoke rising from under the floor plates in the crew cab area. The area of deepest burn was around the automatic gearbox output shaft's UJ, which was consistent with the locus of the fire being directly in this area.

3.4.3 Fire development

Once the fire under the floor plates had become established, the tightly packed grease contaminated buoyancy foam provided a ready source of fuel. As the foam melted into the fire the vapours released would have readily ignited, adding to the intensity of the fire.

The engine compartment’s starboard extraction fan and the engine radiator fan would have drawn the flames and hot gases into the engine compartment through the holes in the transverse bulkhead **(Figure 61)**. From here, the starboard extraction fan forced the smoke and flames through the engine compartment’s starboard ventilation void space, pre-heating and subsequently igniting the buoyancy foam contained within it. Again, this is supported by witness accounts that described the smoke as being initially white/grey and then turning black. This is consistent with the fire laboratory’s findings that, when burning, the low-density foam (packed in the central void space) and the high-density foam (packed in the engine compartment’s ventilation void spaces) produced light grey and black smoke respectively.

The smoke and flames exited the vehicle through the starboard ventilation void space outlet vent. The fan would have continued to run until its wiring failed or its casing melted. After which, the hot gases travelling through the void space would have created a chimney effect; drawing cold air into the engine compartment through the vents in the hatch covers to feed the fire. The fire under the floor plates also burnt through the flexible air hoses that supplied the compressed air to the foot brake distribution valve. The subsequent release of the compressed air would have added to the intensity of the fire for a short period until the three air reservoirs emptied.

As the fire developed, it spread to the passenger compartment, causing the side curtains and forward section of seating to be consumed. The flexible fuel hose located under the dashboard burnt through because it did not meet the required fire test standard. This would have caused a small amount of diesel fuel to feed the fire until the fuel supply line emptied.

The large hole in the transverse bulkhead below the crew cab allowed the fire to spread quickly to the starboard ventilation void space. Had the converted DUKW's passenger space and engine compartment been separated by an insulated, gas-tight bulkhead, in accordance with the regulatory requirements, the fire would not have spread so quickly.

3.4.4 Source of ignition

In determining the cause of the fire on board *Cleopatra* a number of potential ignition sources were considered against the circumstances prevailing at the time. These included:

- Contact between the buoyancy foam and the unlagged section of the engine exhaust in the engine compartment’s starboard ventilation void space.
- Overheating of the band brake.
- Leaks from the engine fuel oil system, the hydraulic oil steering system and drivetrain gearboxes.
- Electrical short-circuit, overload and component defects.

The fire investigation determined that none of the above were contributory.

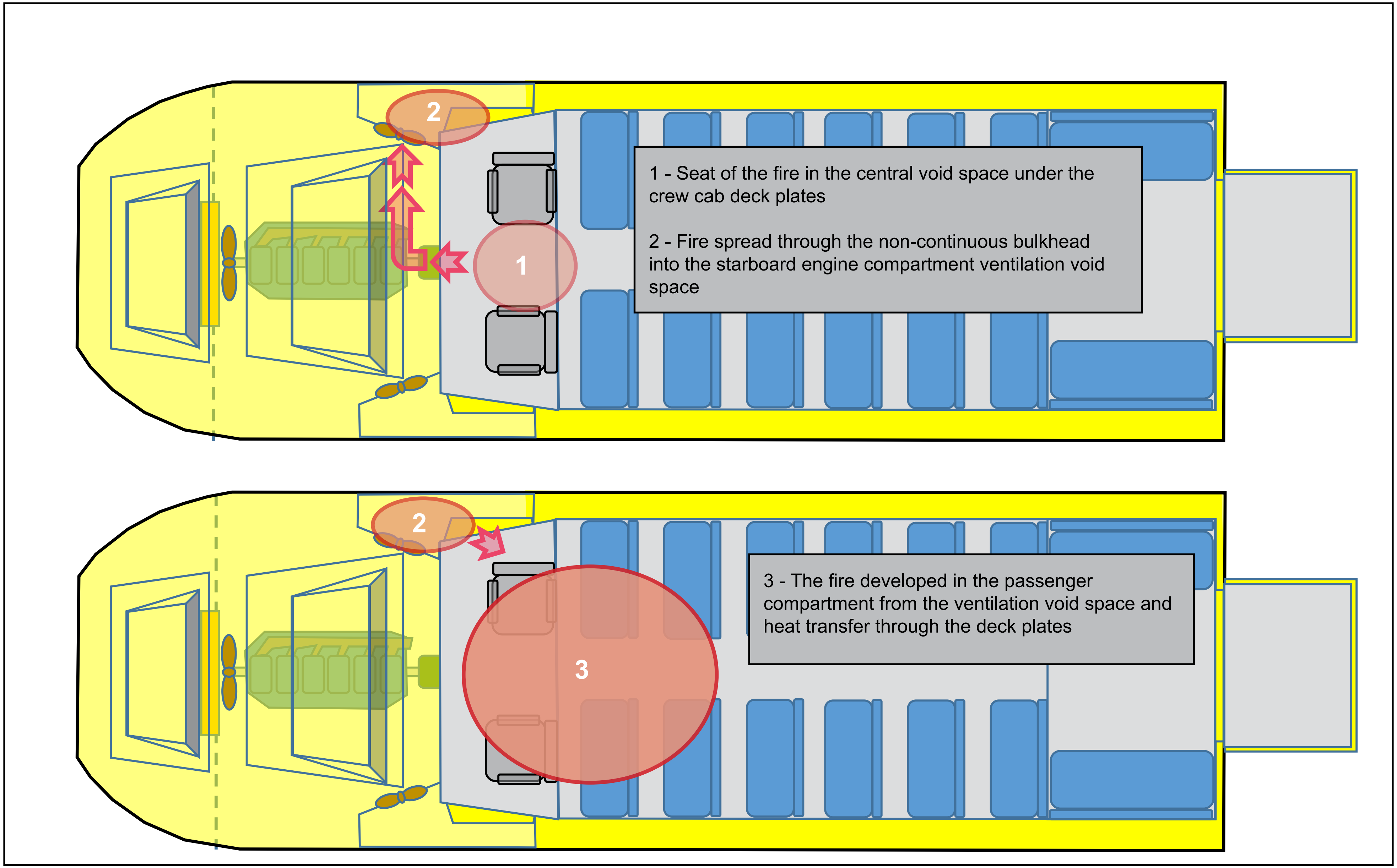

Figure 61: Fire development

Self-heating[27] of the grease on the buoyancy foam and heat generation as a result of friction between the foam and the drive shaft arrangements were also considered.

Laboratory analysis of the UJs **(Paragraph 2.12.2)** used to connect the splined drive shaft to the automatic gearbox and the MTB determined that both had suffered excessive wear. In particular, the laboratory report identified that the journal cap supporting the needle roller bearings on one of the arms fitted to the forward UJ had fractured circumferentially and that the needle roller bearings had suffered from pre-existing overheating. The report identified that temperatures of between 300 and 400°C would be required to cause the bluing that was evident on the needle rollers. These temperatures would have been sufficient to ignite the foam, particularly the fine shards of grease contaminated foam that were present at the time.

Having considered all the evidence, the MAIB fire investigation concluded that the most likely source of ignition was contact between the grease contaminated buoyancy foam and the overheating UJ that connected the MTB drive shaft to the automatic gearbox output shaft. Regardless of the mechanism of ignition, it is almost certain that the packing of unsecured and unprotected buoyancy foam around moving machinery in the central void space introduced the circumstances that led to the fire.

3.4.5 Failure of the universal joint

The packing of additional buoyancy foam around the drivetrain and within the ventilation void spaces made it more difficult to carry out basic greasing routines. It also changed the characteristics of the environment within the engine compartment and in the spaces surrounding it. The foam created an insulating effect that had increased the engine compartment temperature and reduced the flow of air over the shaft lines. This reduced the dissipation of heat from the central void space. This phenomenon was evident from the reduced temperatures experienced in the passenger compartment and was acknowledged by LDT when DUKW *Elizabeth* suffered a similar UJ failure a couple of months earlier **(Paragraph 2.18.2)**.

The temperature increase around the drivetrain would have reduced the viscosity of the grease within the UJs, and increased the likelihood of the grease deteriorating or being expelled from the rotating UJs. The most common causes of UJ failures are lack of lubrication and shaft misalignment. Both will cause the UJ to overheat and turn blue. The joints start to squeak and cause vibration that increases with speed, before typically failing with a loud *clunk*. This was the case with *Elizabeth* and would almost certainly have happened on *Cleopatra* had the fire not broken out.

LDT was under pressure to meet the damaged survivability standard and gave insufficient attention to the adverse effects and the risks associated with packing foam close to the unguarded drivetrain and unlagged exhausts. The DUKW operator chose to accept the increased maintenance burden and continued to operate its vehicles with an elevated risk of mechanical failure and fire.

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[27] Self-heating of lubrication products on open cell insulation is a recognised problem and typically occurs in areas with a high ambient temperature.

3.4.6 Material condition of *Cleopatra* and London Duck Tours fleet

After *Cleopatra*'s fire, the LDT fleet was subject to a similar level of scrutiny to that of the vehicles in Liverpool. In general, the LDT vehicles were found to have been well maintained and in a sound material condition. It was also evident that the company had invested significant resources to improve the operational performance and corrosion resistance of its vehicles.

3.5 VESSEL SURVIVABILITY

3.5.1 Regulatory compliance

To meet the damaged survivability standard set out in MSN 1699(M), the UK's Class V DUKWs were required to have sufficient residual buoyancy to remain afloat and upright in the fully flooded condition. To achieve this, the Liverpool and London based operators undertook to insert buoyancy foam into the hulls of their vehicles. In addition to providing 110% buoyancy, the operators were required to ensure that any buoyant material used was secured against movement and protected against deterioration.

Following the MCA's intervention in London in 2008, BCTQ calculated that about $9m^3$ of closed cell foam was needed to provide 110% buoyancy on board the LDT DUKWs. Despite this, and the sinking of *WQ4* and *WQ1*, LDT continued to operate its vehicles on the River Thames with less than 70% of the calculated quantity of buoyancy foam required to stay afloat in the fully flooded state. LDT only took steps to address the shortfall once the long-standing non-compliance had been identified by the MCA.

The evidence compiled during this investigation overwhelmingly showed that the UK operators had not, and could not achieve the mandated damaged survivability standard. Had one of LDT's DUKWs suffered a similar level of flooding to that of *WQ1*, it would probably have sunk equally as fast.

3.5.2 The use of buoyancy foam

The military DUKW was designed over 70 years ago for mass production during WW2 and was expected to have a very short operational life. DUKWs had an open hull with no watertight segregation and relied wholly on high capacity de-watering pumps to survive incidents of flooding.

In its report into the sinking of *Miss Majestic* in 1999 **(Paragraph 1.16.3)**, the NTSB concluded that it had been a flaw in the design of DUKWs, when they were originally converted for use as APVs, not to provide adequate reserve buoyancy to ensure the vehicles remained afloat in the flooded condition. Despite its recommendation to US operators to retrospectively provide reserve buoyancy through passive means, the majority of US operators (and others across the world) have yet to satisfy the survivability requirements that have always been present within the UK. This is not an indication that the regulators and operators in the US, and other countries, are willing to accept lower standards and a higher level of risk, more an acknowledgement that these vintage vehicles cannot easily be modified to meet modern survivability standards.

DUKWs have a very high weight to size ratio and, as open boats, a high volume of buoyancy foam is needed to satisfy the damaged survivability standard. Inserting such large quantities of buoyancy foam introduces many problems for the operators and for surveyors. Specifically, it impedes access for routine cleaning, maintenance and inspection, and increases the risk of water entrapment and resultant corrosion. The use of individually cut foam sheets, rather than the previously recommended pre-formed solid foam blocks, compounds the problem as the foam takes longer to remove and refit, and increases the risk of movement.

3.5.3 Buoyancy foam calculations

Once the MCA's investigation into the sinking of *WQ4* established that the Liverpool DUKWs were deficient of buoyancy foam, TYD sought the assistance of BCTQ. BCTQ was contracted to provide a reserve buoyancy calculation for a typical Liverpool DUKW, and identify locations and approximate the space available to fit buoyant material. BCTQ followed a similar process to the one it had adopted in London in 2008, and estimated that 9.7m^3 of buoyancy foam was needed for an 8.3t vehicle.

The sinking of *WQ1* so soon after the MCA's intervention was of great concern. It cast doubt on the validity of the theoretical calculations conducted by BCTQ and the practicalities of inserting and maintaining the prescribed quantities of buoyancy foam in the hull of a DUKW. When the MCA discovered that the LDT vehicles were also deficient of buoyancy foam, LDT initially increased the quantity of foam in its vehicles to 9.05m^3; the volume calculated by BCTQ in 2008. This was 0.65m^3 less than that calculated for an 8.3t Liverpool DUKW; however, the weight of some of the London vehicles had increased to over 9t. These discrepancies led the MCA to carry out its own calculations and instruct LDT to further increase the volume of foam to 10.6m^3.

It was clear from the practical trials and reconstruction conducted by the MAIB in July 2013 **(Paragraph 1.10.3)** that:

- The calculated volume of foam required to provide 110% buoyancy could not physically be fitted into the locations designated in the BCTQ report.
- The insertion of 7.93m^3 of foam into the designated locations kept *WQ1* afloat[28] but rendered the vehicle inoperable.
- The closed cell buoyancy foam used by TYD was between 5 and 20% denser (heavier) than its specification indicated and therefore calculating the volume of foam by weight could not be relied upon.
- At best, *WQ1* could only have had about 7m^3 of buoyancy foam on board when the MCA allowed it back onto the water.
- The assumption that TYD's DUKWs had the space to insert 12m^3 of buoyancy foam was wholly unrealistic.

Despite these findings, and MAIB recommendation 2013/223 **(Paragraph 2.2)**, LDT continued to stuff increased quantities of foam into its vehicles without the potential adverse consequences being properly assessed.

[28] As evident from BCTQ's buoyancy assessments for both TYD and LDT vehicles, the inherent buoyancy of each converted DUKW can vary significantly, and therefore the results of the MAIB's reconstruction should not be used as a benchmark for other similar vehicles.

Theoretical calculations had indicated that the UK's converted DUKWs were able to meet the damaged survivability standard through the insertion of buoyancy foam alone. However, historical evidence and practical trials conducted by the MAIB demonstrated that they could not.

3.6 PASSENGER AND CREW SURVIVABILITY

3.6.1 Risk of entrapment

When *WQ1* sank, the driver and several of the passengers were still inside the vehicle. Fortunately, when the bow of the vehicle touched bottom, the stern remained above water and they were able to escape through the side and stern windows. The last passenger to escape, the mother of the 2 year old child, climbed over the passenger compartment access door onto the boarding platform **(Figure 62)**.

The NTSB's *Miss Majestic* report identified that the vehicle's canopy had probably hampered the escape of many of those who died. The guidance provided in the USCG's NVIC1-01 contained several recommendations aimed at reducing the risk of entrapment. This led APV operators in the US, and in other countries, to redesign their vehicles' canopies, windscreens and side curtains, and improve their procedures to help increase passenger survivability.

WQ1 and *Cleopatra* both had solid canopy roofs and transparent plastic side curtains. Had it been raining at the time of the accidents, it is likely that the side curtains would have been closed. This would have made it significantly more difficult to escape from the passenger space. Similarly, had the water in Salthouse Dock been deeper, or the additional foam not been fitted the previous month, the likelihood of entrapment would have been higher.

3.6.2 The risk of drowning

To assist the passengers' survival in the water the DUKWs were equipped with PFDs, buoyant apparatus and lifebuoys. According to the TYD and LDT abandon ship procedures, the crew were required to help the passengers to don their PFDs and launch the buoyant apparatus before evacuating their vehicles. During both accidents, the confined nature of the passenger compartments significantly hampered the crews' ability to assist the passengers and control the abandonment process. In both cases, the crew did not have the time to launch the buoyant apparatus and most of the passengers, some of whom could not swim, and crew were forced to enter the water without a PFD.

The decision concerning when to wear or inflate a PFD in an enclosed or semi-enclosed boat, is a regular topic of debate. It is obvious that the most effective way of ensuring that passengers are wearing correctly donned PFDs when they abandon a boat is to insist that they wear them at all times on the water. However, it might be argued that this would further increase the risk of passenger entrapment; it might also deter potential customers from going on an amphibious sightseeing trip.

As the passengers were expected to don their PFDs before evacuating into the water, and TYD offered the opportunity to wear one while on the water, the argument against insisting that all passengers wear a PFD during the waterborne section of the DUKW tours appears to be weak.

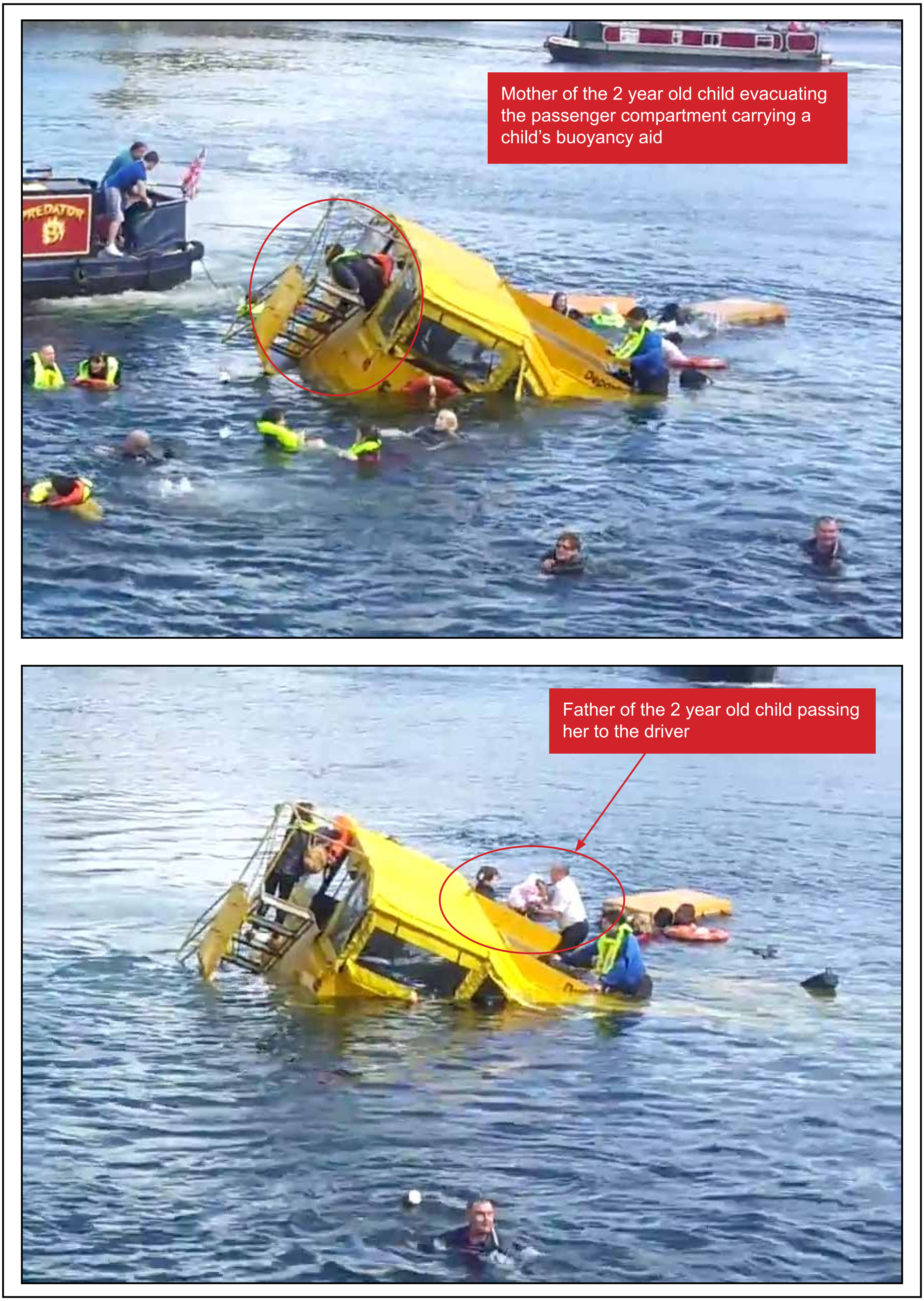

Figure 62: The last of the passengers to escape from *Wacker Quacker 1*'s passenger compartment

Both TYD and LDT DUKWs have been evacuated successfully on a number of occasions over the years following relatively minor accidents and incidents. However, the nature of the current UK DUKW fleets means that serious fire and flooding events give the occupants very little time in which to assimilate the danger, prepare themselves to abandon ship, and to actually abandon. Wearing PFDs throughout the waterborne journey would significantly reduce the time needed to prepare for abandonment should it become necessary, but only if this does not result in an increased risk of entrapment.

3.6.3 The Irish model

In Ireland, APV operators have been permitted to operate vintage DUKWs without having to provide any residual buoyancy. To mitigate the consequences of serious flooding, the Irish regulator required the operators to:

- Fit external buoyancy tubes **(Figure 63)** designed to slow the sinking process and make the vehicle sink bodily.

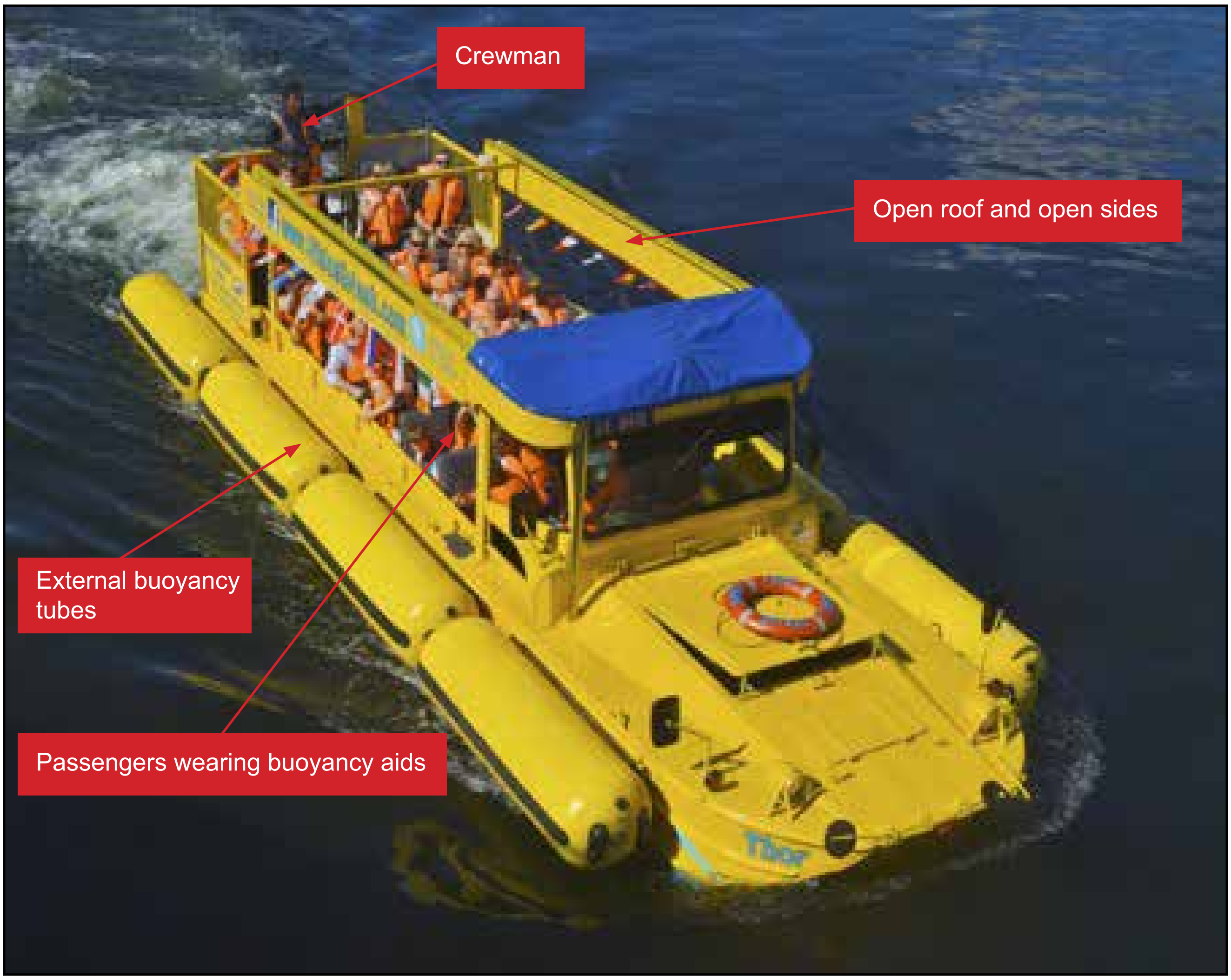

Figure 63: Dublin DUKWs operating with external buoyancy tubes and open canopy

- Retract the canopy roof and open the side curtains prior to entering the water.

- Require passengers and crew to wear PFDs while on the water.

- Provide a fast rescue craft, rescue crew and an inflatable liferaft at the slipway.

- Limit operations to a non-tidal area.

This approach focused on passenger survivability by reducing the risk of entrapment and drowning, rather than vehicle survivability, and introduced several of the interim measures recommended by the NTSB following the sinking of *Miss Majestic* **(Paragraph 1.16.3)**. The Irish model demonstrates that open topped APVs can be operated successfully in similar weather conditions to those experienced in the UK, and that passengers are willing to wear PFDs.

3.7 ROLE OF THE REGULATORS

3.7.1 Effectiveness of survey and inspection regimes and unscheduled interventions

It was apparent from MCA records that the maritime regulator had long-standing reservations over the safe operation and seaworthiness of DUKWs. Despite these concerns, and the maritime regulator's periodic survey and inspection regime and its unscheduled interventions, the Liverpool and London DUKWs continued to operate for over a decade without complying with the mandated damaged survivability standard.

Prior to the sinking of *WQ4* in March 2013, surveyors paid little or no attention to the condition or quantity of buoyancy foam during their periodic inspections. This was particularly apparent in Liverpool, where the originally agreed volume of foam required to meet the standard was unknown. The foam that was in place was typically removed prior to the surveyors' arrival at the operators' maintenance garages and it was refitted after they had left. The foam that had been removed was not measured and its condition was not assessed. Following *WQ4*'s sinking, the MCA's Liverpool Marine Office invested significant resources to oversee and verify TYD's buoyancy foam packing process. Having done so, it is difficult to explain how its surveyors concluded that $12m^3$ of foam had been packed into the vehicles.

Although the MCA's intervention did not achieve its aim of keeping a flooded vehicle afloat and upright, fitting more foam into the vehicles did slow the sinking process and helped keep the stern section of *WQ1*'s canopy above water. This gave the passengers and crew vital extra seconds to abandon the vehicle and provided a platform to keep the 2 year old child out of the water **(Figure 62)**. Those two positive outcomes almost certainly helped to save lives.

Buoyancy issues aside, it was clearly apparent from external visual inspection that the Liverpool DUKWs had been poorly maintained, and on closer inspection it was obvious that they were not fit for use as passenger carrying vessels on the water. The Liverpool DUKWs had been allowed to deteriorate progressively over a prolonged period of time. This goes beyond niche APV specific issues and raises serious concerns about the overall effectiveness of the MCA's survey and inspection regime applied to APVs operating in Liverpool.

Had the MCA's survey and inspection regime of DUKW APVs been more effective, the impact of fitting the required amount of foam to achieve 110% buoyancy on the operability of the vehicles would have been immediately apparent and alternative solutions sought. Given that it took around 13 years to discover that both TYD and LDT's DUKWs were operating with insufficient buoyancy, it is extremely fortunate that they did not suffer more serious accidents during this period.

3.7.2 Instructions, guidance and training

The MCA did not provide APV specific instructions, guidance or training to its marine surveyors. There was no prescribed method for verifying the quantity of buoyancy foam on board an operational DUKW, or guidance on how it should be secured and protected.

The lack of guidance and the pressure placed on the MCA by the operators, resulted in a reactive approach being taken to solve a long-standing regulatory non-conformity. In short, the MCA and the DUKW operators became fixated with trying to stuff the necessary volumes of foam into the vehicles' hulls without having properly assessed the consequences.

Had the MCA surveyors had adequate instructions and guidance to refer to, a more consistent approach to the survey and inspection of DUKWs might have been achieved. Furthermore, it is less likely that TYD would have been allowed to resume operations on the water following the sinking of *WQ4*, and LDT might not have been permitted to pack unsecured and unprotected foam so close to the rotating drivetrain.

3.7.3 Sharing of information

The Liverpool Marine Office wrote to MCA headquarters following the sinking of *WQ4* and recommended that the London Marine Office be instructed to check the levels of buoyancy in the LDT vehicles. This information was not acted upon and the LDT vehicles were allowed to continue to operate unchecked.

VOSA had similar long-standing concerns about the safe operation of vintage DUKWs to those of the MCA. The fire on board *Cleopatra* occurred on water and thus came under the regulatory jurisdiction of the MCA; it could just as easily have happened on the road 30 minutes earlier, or later, and therefore have come under the regulatory jurisdiction of VOSA. However, the road regulator was not consulted during the foam packing process.

Neither of the regulators had a designated amphibious vehicle point of contact or industry specific expertise, and there were no arrangements in place for the two DfT agencies to share their knowledge or concerns. The APV industry has to comply with both land based and maritime regulations, and compliance with one is often at odds with those of the other. In such circumstances, compromises in the form of equivalencies need to be agreed. However, it became apparent during the investigation that the APV industry often found it difficult to identify focal points within the two DfT agencies and to obtain a clear and consistent articulation of their regulatory obligations.

While it might be acceptable for historic vehicles to operate on the highway under certain conditions, the nature of the marine environment is such that more modern safety standards need to be applied. Indeed, following the *Marchioness* disaster, Lord Justice Clarke's Thames Safety review concluded that, in general, new safety regulations should be applied to all vessels, whether new or existing. Given the potential for there to be tension between these two approaches there is a need for the regulators involved to cooperate to agree a co-ordinated approach for the guidance of APV operators.

3.8 ROLE OF THE OPERATOR

Regardless of the challenges presented to the MCA and VOSA by this niche industry, the onus to comply with the UK's regulations and deliver a safe sightseeing experience lies firmly with the operator. Both TYD and LDT should have identified that they were unable to safely fit the required volume of buoyancy foam into the spaces designated by their naval architect. This should have been highlighted to the regulators and an alternative solution should have been sought. Operators should not rely on regulators to provide through-life assurances that their vehicles remain compliant and safe. It would be totally impractical to expect MCA surveyors to oversee the removal, measurement and refitting of buoyancy foam on each vehicle during their periodic inspections; the MCA is not resourced to do it, and the operators would not be prepared to pay them to do it.

In addition to never having met the damaged survivability standard, TYD and LDT were slow to react to the safety issues identified following previous accidents and incidents. Some of the circumstances that led to the sinking of *WQ4* and *WQ1* and the fire on board *Cleopatra* had been identified 70 years earlier during WW2 and in more recent accident investigation reports, some of which involved multiple fatalities.

Following the sinking of *WQ4*, LDT wrote to TYD and offered its assistance and advice, but it was apparent that little had been done prior to that to work together in the interests of passenger safety. It was evident during this investigation that some of the UK based APV operators were fiercely competitive and, despite their geographical separation, treated each other's operations as commercial competition.

Amphibious sightseeing tours are very popular with tourists and there appears to be a market for the industry to expand. However, the accidents in Liverpool had a significant impact on the credibility and reputation of other APV operators within the UK and abroad. This was particularly so in London as the LDT vehicles had a very similar appearance to those in Liverpool and the common perception was that both companies operated 70 year old WW2 vehicles. As a small niche industry, it is particularly important that APV operators work together to promote best practice, improve vehicle and passenger safety and re-build public confidence.

3.9 EMERGENCY PREPAREDNESS

3.9.1 General

In order to minimise the consequences of a marine accident, a vessel and its passengers and crew need to be prepared to deal with a variety of emergency situations. Vessels are prepared through design and the provision of LSA and other safety equipment. Vessel owners and operators prepare their crews by providing them with guidance and procedures, and through the delivery of training. To ensure training has been effective and emergency procedures are fully understood, ships' crews should conduct realistic emergency response drills on a regular periodic basis.

Ships' crews prepare their passengers to deal with emergencies through the provision of instructions, demonstrations and, in some cases, the wearing of PFDs. TYD and LDT prepared their passengers through the delivery of verbal safety briefs and the provision of PFD donning instructions on the backs of the passenger seats. LDT also gave a practical PFD donning demonstration.

3.9.2 Emergency preparedness – *Wacker Quacker 1*

The lifejackets on board *WQ1* were stored out of sight, in plastic packaging, under a seat at the back of the vehicle. The straps on the children's buoyancy aids had not been fully extended. This meant that the parents of the 2 year old were unable to put one on their daughter before evacuating the passenger space. *WQ1*'s buoyant apparatus was stowed on the canopy roof. The capacity of the LSA on board *WQ4* and *WQ8* was less than the maximum number of persons the vehicles had been certified to carry.

The crew on board *WQ1* had both received training and had participated in emergency drills, but the abandon ship drills carried out by the crew were not in accordance with the procedure in TYD's safety management system. During the drills the crew practised evacuating the passengers onto pontoons at the edge of the docks rather than into the water. The master had experienced problems on the water in the past and on those occasions he had evacuated his passengers onto pontoons. It was evident that the master and his driver were not familiar with the procedure for abandonment on the water and therefore their training and drills had not been effective.

Prior to entering the water in the build-up to the accident, *WQ1* was parked on the road at the top of the slipway for just 15 seconds. This indicates that the safety brief was either extremely short or was given on the road prior to arriving at the docks. It was apparent from the feedback provided to the MAIB by the passengers that the safety brief given by the crew had not been taken seriously, and was ineffective. The MCA had recently written to TYD listing its concerns about the standard of the company's pre-splashdown safety briefs and instructed it to provide a lifejacket donning demonstration. However, the company continued to deliver its safety briefs in a jocular manner and did not show passengers how to don their lifejackets. Subsequently, the majority of the passengers did not know where their lifejackets were stowed, how to put them on or how to inflate them.

In earlier iterations of TYD's *Safety Policy and General Safe Operational Procedures* manual, the pre-splashdown safety brief **(Annex C)** was more comprehensive and included practical demonstrations. Passengers might have an expectation that they are going to be entertained by the crew during their tour, and might not want to listen to a safety brief. Nonetheless, it is essential that they are given the best opportunity to understand the safety procedures and know how to put on and use a PFD. In order to achieve this, the safety brief should be clear and concise and be delivered with conviction and authority.

It is clear that *WQ1*, its crew and their passengers had not been adequately prepared to deal with the emergency situation. The lifejackets were not readily available, many of the passengers did not know how to don them or inflate them and the crew were not familiar with the abandon ship procedure.

3.9.3 Emergency preparedness – *Cleopatra*

As was the case in Liverpool, *Cleopatra*'s crew had little time to react to a rapidly escalating situation. However, the vehicle, its crew and their passengers had been better prepared to deal with it. It was clear from the passenger feedback that, although given in a light-hearted manner, the safety brief was more effective than that given on board *WQ1*, and the passengers were shown how to don their buoyancy aids. Further, the buoyancy aids on board *Cleopatra* were readily accessible in racks above the passengers' heads. However, the buoyancy aids had been stowed in plastic bags that were difficult to remove and their straps had not been fully extended. The obvious adverse implications of this had previously been pointed out in the MAIB's 2001 *Beatrice* report **(Paragraph 1.16.2)**.

The crew on board *Cleopatra* had both received training and had participated in emergency drills. According to LDT's abandon ship procedure the crew were expected to launch the buoyant apparatus and then seat the passengers on top of them. The buoyant apparatus was not designed to support their rated capacity of people out of the water. Although it might be appropriate to place small children or injured and weak survivors on top of the rafts, attempts to seat all the passengers on them would probably be unsuccessful and would delay the abandonment process.

3.10 EMERGENCY RESPONSE – *WACKER QUACKER 1*

3.10.1 Raising the alarm

The crew of *WQ1* were unconcerned when the DUKW failed to climb the slipway as they had experienced this problem earlier in the day and on several occasions in the past. The driver and the master thought the vehicle had a gearbox problem and focused their attention on resolving it. They did not inform the operations office or explain to the passengers what had happened.

When *WQ1* began to flood the vehicle's electric bilge pumps started automatically and some of the passengers tried to alert the crew. Initially, the crew appeared to ignore the shouts from the back of the vehicle and the bilge pump alarms. Again, they were used to water entering the hull and might have initially underestimated the rate of ingress.

When the crew realised the severity of the situation, the master made his way to the back of the vehicle. The driver was unable to find the master's mobile phone and therefore did not alert the operations office or emergency services. Fortunately, the incident occurred in a very busy part of the South Docks complex where immediate assistance from bystanders was available.

3.10.2 The abandonment

As *WQ1* sank, the majority of the passengers and its two crew entered the water, many without lifejackets. Those who had them were either unable to put them on properly or could not inflate them. Some passengers swam ashore, but the majority were rescued from the water by the people on board three recreational narrowboats that had been berthed in Salthouse Dock.

WQ1’s crew might have thought that they had time to co-ordinate and control the abandonment process following the recent addition of buoyancy foam. However, vital time was lost trying to pass the lifejackets forward to the passengers at the front of the vehicle and having to remove them from their packaging. Instinctively, the passengers used their own initiative and abandoned *WQ1* with or without their lifejackets. Some of the weaker swimmers and smaller children were able to hold onto the buoyant apparatus that had been launched earlier by a 70 year old passenger who was grandfather to two of the children on board.

WQ1’s crew were unable to effectively assist the passengers because of the confined nature of the vehicle and a basic lack of emergency preparedness. According to TYD's abandon ship procedure, the crew were expected to launch the buoyant apparatus and help the passengers don their lifejackets prior to abandonment. Had the crew been able to calm and control the passengers, and attempted to follow the company's abandon ship procedure, it is likely that lives would have been lost because of the speed at which the vessel sank. Given the circumstances of this accident, the company's emergency response procedures proved to be unrealistic.

3.10.3 Shore based emergency response

Within 10 minutes of the alarm being raised by members of the public the emergency services (police, fire and ambulance) were on site and had taken control of the incident. By this time, the passengers and crew had either swum ashore or been recovered onto the narrowboats.

During the rescue phase, TYD did little to assist and its rescue boat remained alongside in Salthouse Dock. There was no nominated muster point and some passengers dispersed from the scene before a headcount was carried out. Although there were no major injuries, it took the police several hours to account for everyone. Had the company prepared a major incident response plan and carried out regular drills to challenge and test it, its contribution to the rescue effort might have been more significant.

The efforts of the narrowboat crews were instrumental in the safe recovery of many of those in the water, particularly as some were struggling to, or could not swim. The young man who jumped into the water from the bow of *Predator 3* **(Figure 64)** to assist those struggling in the water was fully aware of the risk he was taking, and should be commended for his bravery.

3.11 EMERGENCY RESPONSE – *CLEOPATRA*

3.11.1 Raising the alarm

At the first sight of smoke the tour guide advised passengers of a possible problem, and the master steered *Cleopatra* towards the shore in the belief that *Cleopatra* had an exhaust problem. The smoke soon escalated to fire, and just over a minute later the master attempted to raise the alarm using his VHF radio. Within seconds, radio communication was lost and it took the intervention of an unknown third party to inform VTS that *Cleopatra* was on fire.

Figure 64: Member of the public jumping from *Predator 3* to help passengers in the water

In the event of a vessel being in *grave and imminent danger*[29], emergency protocol requires a stricken vessel to transmit a distress alert. In *Cleopatra*'s case this did not happen. The master's verbal distress call was not preceded by the signal word "*Mayday*" and was not transmitted on channel 16, the dedicated VHF channel for safety alerting.

The distress protocol for vessels fitted with DSC enabled radios is for the radio operator to send an initial alert by DSC before commencing voice communications. On most radios the DSC function is activated by a push button that needs to be held depressed for between 3 and 5 seconds. The basic DSC distress alert then automatically transmits the vessel's identification, its position and time of transmission without any further input from the radio operator. Although it is tempting and comforting to use verbal communications in such a situation, the same information as given by DSC cannot be verbally transmitted in 3 to 5 seconds. Additionally, erroneous positional information is often given during verbal communications by operators under pressure. In many circumstances, these vital early seconds can make the difference between a successful rescue and the loss of life.

3.11.2 Fire containment and fire-fighting

Although the fire had started under the deck plates in the crew cab area, the early indications were that the crew were dealing with a problem within the engine compartment. When it became obvious that there was a fire on board *Cleopatra*, the master took the decision to drive his vehicle onto the nearest riverbank. Once aground, the master's initial priority was to use the engine to keep his vehicle

[29] The unambiguous internationally recognised interpretation of a vessel in distress.

pressed onto the riverbank. When the engine was stopped the crew were unable to close the ventilation void space fire dampers because the ‘R’ clips had become too hot and the heat and smoke generated by the fire quickly forced them to move away from the crew cab area. The engine compartment’s fixed fire-extinguishing system was not activated and none of the vehicle’s portable fire-extinguishers were used to fight the fire.

This was a serious fire that spread quickly, and it is for just such emergencies that fire drills are conducted. In this instance, onboard fire-fighting would have been only partially effective because the fire was not in the engine compartment. Therefore, the master’s decision to drive his vehicle aground proved to be a sound one and significantly reduced the risk to life during the abandonment. Nonetheless, it would have been appropriate for the crew to isolate the fuel supplies, close the engine vent fire dampers and operate the engine compartment’s fixed fire-extinguishing system as soon as possible.

3.11.3 The abandonment

When the fire broke out on board *Cleopatra* most of the passengers grabbed buoyancy aids and moved towards the back of the vehicle, away from the flames. The tour guide was unable to assist or control the passengers and had to force his way past them to get to the stern door. Unable to open the door, some passengers, understandably, abandoned into the water without grabbing or donning a buoyancy aid.

The speed at which the fire escalated gave little or no time for the crew to prepare the passengers and the vehicle’s LSA for a controlled abandonment. Similar to the abandonment of *WQ1* in Liverpool, the passengers on board *Cleopatra* were forced to act on instinct and exit the passenger space under their own initiative. Had the side curtains been down, the conditions within the passenger space would have deteriorated even more rapidly and it would have been more difficult to escape.

3.11.4 Shore based emergency response

Within 2 minutes of the fire breaking out, *Cleopatra*’s passengers and crew had been recovered from the water by the crew of three passenger carrying RIBs. LFB’s fireboat, *Firedart*, and a shore-side fire appliance was on the scene within 5 minutes, and the fire was quickly extinguished. The police and ambulance services, and the RNLI were also quickly on the scene and soon established that all passengers and crew had been recovered and were safe.

The location and time of the accident was extremely fortuitous. Had the fire and subsequent abandonment happened at high water, or in mid-river, the occupants would have had to abandon into deeper water, which would have increased the likelihood of serious injury and loss of life. Although the emergency services responded quickly, the commendable actions of those on board the Thames RIB Experience boats was fundamental to the safe recovery of *Cleopatra*’s passengers and crew.

SECTION 4 - CONCLUSIONS

4.1 THE SINKING OF *WACKER QUACKER 1*

1. *WQ1* sank because it suffered rapid uncontrolled flooding, and did not have the mandated level of residual buoyancy needed to keep it afloat in its fully flooded condition. [3.3.1]

2. *WQ1* began to flood when two holes were torn into its hull by the forces generated when its propeller was fouled by a discarded car tyre. It became fully flooded because its electric powered bilge pumps were unable to cope with the rate of water ingress. [3.3.1]

3. Had TYD learned lessons from previous similar hull failures or followed the advice of LDT and reinforced *WQ1*'s propeller shaft tunnel plating, the hull might not have failed. [3.3.2]

4. *WQ1* was in an extremely poor condition. Its hull was heavily corroded and was covered with a patchwork of unapproved substandard repairs, it was mechanically unreliable, and regularly failed to climb out of the dock. The vessel was not seaworthy and it should not have been operating on the water. [3.3.4]

5. TYD's vehicles suffered a high number of mechanical breakdowns, hull failures and flooding incidents during the months leading to the sinking of *WQ1*. The operator was aware of the potential consequences of flooding but continued to take passengers onto the water in unseaworthy vehicles. [3.3.5]

6. The MCA's survey and inspection regime in Liverpool proved to be ineffective; the material condition of the TYD fleet was allowed to progressively deteriorate to an unsafe condition over a prolonged period of time. [3.7.1]

7. *WQ1*, its crew and their passengers had not been adequately prepared to deal with the emergency situation. The lifejackets were not readily accessible, many of the passengers did not know how to don them or inflate them and the crew were not familiar with the abandon ship procedure. [3.9.2]

8. TYD did little to assist the emergency response effort, its rescue boat was not used and a passenger headcount was not carried out. [3.10.3]

4.2 THE FIRE ON BOARD *CLEOPATRA*

1. The locus of the fire on board *Cleopatra* was under the crew cab floor plates in the hull's central void space. [3.4.2]

2. The buoyancy foam that had recently been packed into the central void space provided a ready source of fuel. [3.4.3]

3. Had an insulated gas-tight bulkhead been fitted between *Cleopatra*'s accommodation areas and engine compartment, in accordance with passenger ship construction standards, the fire would not have spread so rapidly through the engine compartment to the passenger space. [3.4.3]

4. The packing of unsecured and unprotected buoyancy foam around the vehicle's engine compartment and drive shafts introduced the circumstances that led to the fire. [3.4.4]

5. The most likely source of ignition was contact between grease contaminated buoyancy foam and an overheating drive shaft universal joint. [3.4.4]

6. LDT gave insufficient attention to the adverse effects of packing buoyancy foam close to moving machinery and unlagged exhausts, and allowed its vehicles to operate with an elevated risk of mechanical failure and fire. [3.4.5]

7. The master's decision to drive his vehicle aground proved to be a sound one and significantly reduced the risk to life during the abandonment. [3.11.2]

8. *Cleopatra*, its crew and their passengers were better prepared to deal with an emergency situation on the water. However, the speed at which the fire escalated gave little or no time to conduct a controlled abandonment. [3.11.3]

9. Had the fire and subsequent abandonment happened at high water, or in mid-river, the likelihood of serious injury and loss of life would have been significantly higher. [3.11.4]

4.3 COMMON SAFETY ISSUES

1. For over a decade, little attention was given to buoyancy foam by the operators and the regulators, and the UK's Class V DUKWs were operated without having met the mandated damaged survivability standards set out in MSN 1699 (M). [3.5.1]

2. Had a London DUKW suffered a similar level of flooding to that of *WQ1*, it would probably have sunk equally as fast. [3.5.1]

3. The UKs converted DUKWs could not safely meet the regulatory standards for damaged survivability through the insertion of buoyancy foam alone. [3.5.3]

4. The combination of a lack of guidance and instructions and pressure from the DUKW operators led to a reactive approach being taken by the MCA to a long-standing regulatory non-conformity and a fixation with stuffing foam into restricted spaces. [3.7.2]

5. The fire on board *Cleopatra* occurred on water and thus came under the regulatory jurisdiction of the MCA. It could just as easily have happened on the road, and therefore have come under the regulatory jurisdiction of VOSA. [3.7.3]

6. The MCA and VOSA both had long-standing concerns about the safe operation of the converted DUKWs, but they did not share their concerns and knowledge, or communicate with each other to address common issues and minimise regulatory conflicts. [3.7.3]

7. The confined nature of the passenger compartment made it extremely difficult for the crew to control and assist the passengers and increased the likelihood of entrapment. [3.11.3]

8. It was extremely fortunate that all on board *WQ1* and *Cleopatra* were able to evacuate into the water unharmed. In both cases the passengers were forced to act on instinct and exit the vehicles under their own initiative. Had:

- the quantity of buoyancy foam on board *WQ1* not been increased 2 months before the accident;
- the depth of water in Salthouse dock been greater;
- *Cleopatra*'s master been unable to run his vehicle aground;
- it been raining on the day of either accident (and hence the side windows being closed); or
- the crews of *WQ1* and *Cleopatra* followed their company's abandon ship procedures by controlling the passengers and passing out lifejackets before leaving their vehicles;

the risk of entrapment and the likelihood of loss of life would have been considerably higher. [3.10 and 3.11]

SECTION 5 - ACTION TAKEN

5.1 MAIB ACTIONS

The **Marine Accident Investigation Branch** has:

- Issued safety bulletin SB3/2013[30], containing recommendation S2013/233, which recommended the MCA to:
  - *In addressing recommendation 2013/221, ensure that the means used by DUKW operators to achieve the required standard of buoyancy and stability for their vessels does not adversely impact on their safe operation. Furthermore, these vessels should not be permitted to operate until satisfactory levels of safety can be assured under all feasible operating conditions.*

5.2 ACTIONS TAKEN BY OTHER ORGANISATIONS

The **Maritime and Coastguard Agency** has:

- Carried out an internal investigation into the file and record management in its Liverpool and Orpington Marine Offices with particular attention given to MCA oversight of DUKW APVs. As a result of its findings it has:
  - Taken steps to improve the standards of record management at, and the sharing of information between its Marine Offices.
  - Required APV operators to submit documentary evidence to demonstrate compliance with their statutory obligations.
  - Produced a methodology for ensuring the correct quantity of buoyancy foam is in place.
- Commissioned an independent DUKW regulatory compliance study and outlined a phased approach to the development and implementation of a mandatory technical standard for amphibious passenger vehicles.
- Enforced the regulatory requirement to fit an insulated fire protection bulkhead between the engine compartment and accommodation space on existing DUKWs.
- Has worked with LDT to develop a ‘reference DUKW’ standard and, as a result, has approved a series of design modifications and authorised the company to resume its operations on the River Thames.

DfT Traffic Commissioner has:

- Withdrawn Pearlwild Ltd’s Passenger Service Vehicle licence.

[30] SB3/2013 – *The sinking of the DUKW amphibious vehicle Wacker Quacker 1 in Salthouse Dock, Liverpool on 15 June 2013, and the fire on board the DUKW amphibious vehicle Cleopatra on the River Thames, London on 29 September 2013.*

Pearlwild Ltd has:

- Placed TYD into administration and is no longer operating APVs.

London Duck Tours Ltd has:

- Modified its DUKWs to satisfy the damaged survivability standard by using a combination of buoyancy material and compartmentalisation **(Annex F)**. The modifications include:

    - The installation of an insulated gastight and watertight transverse bulkhead between the engine compartment and the passenger space.

    - Mounting the passenger seats on top of individual air tight aluminium buoyancy tanks.

    - Replacement of the steel deck plates with aluminium.

    - The provision of dedicated void spaces for the insertion of buoyancy by the relocation of the fuel tank and the ancillary machinery and services under the passenger compartment floor plates.

    - Boxing in the drivetrain journal bearings and UJs.

    - The replacement of the original fuel lines with approved solid drawn and flexible steel pipework.

    - Changes to the engine and engine compartment cooling air system.

    - The provision of a fire damper for the forward engine compartment hatch cooling air vent.

SECTION 6 - RECOMMENDATIONS

The **Maritime and Coastguard Agency** and the **Driver and Vehicle Standards Agency** are recommended to:

2014/153 Identify single points of contact for amphibious vehicle issues and put processes in place to allow them to work together, in consultation with the industry, to explore potential cross agency synergies, identify regulatory conflicts and agree a coherent approach to the survey and certification of new and existing amphibious passenger vehicles.

The **Maritime and Coastguard Agency** is recommended to:

2014/154 Provide amphibious vehicle survey guidance and instructions to its surveyors.

2014/155 Work with industry to develop an amphibious vehicle operators' code of practice.

2014/156 Ensure that measures to reduce the risk of passenger entrapment and improve the levels of passenger survivability are included in its proposed technical standard for amphibious passenger vehicles.

2014/157 Require existing DUKW operators, which may choose to rely on the insertion of buoyancy foam to meet the required damaged survivability standards, to demonstrate through risk based analysis that the foam does not adversely affect the safe operation of the vehicles.

London Duck Tours Ltd is recommended to:

2014/158 Use the safety lessons identified in this report to take further action to ensure, as far as is reasonably practicable, its vehicles, crew and passengers are best prepared to deal with emergency situations. In particular, attention should be given to:

- The readiness and use of PFDs: the practicalities of the current arrangements should be reviewed and consideration given to requiring all passengers to wear PFDs whenever DUKWs are waterborne.
- Establishing appropriate and achievable emergency procedures: these should include the marshalling of passengers, alerting potential responders and abandonment.
- Development of effective training drills.
- Engine compartment shut-down and fire-fighting.
- Lowering the risk of passenger and crew entrapment: assess in particular whether the current canopy arrangements are appropriate.

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

Marine Accident Report

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