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- safety data recording, analysis and research
- fostering safety awareness, knowledge and action.

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ATSB TRANSPORT SAFETY REPORT
Marine Occurrence Investigation No. 288
MO-2011-007
Final

Breathing apparatus air compressor explosion on board the woodchip carrier *Universal Gloria* off Eden, New South Wales

11 October 2011

Abstract

At about 1450¹ on 11 October 2011, the third mate on board the Panama registered woodchip carrier *Universal Gloria* suffered burns to his hands and face when the air compressor he was using to fill an oxygen breathing apparatus (OBA set) cylinder exploded.

The ATSB investigation found that the explosion occurred as a result of a fire that started within the compressor when oil ignited in the hot oxygen-rich environment.

The investigation identified three safety issues. The crew were not appropriately trained or drilled in the operation and maintenance of the ship's OBA sets; the ship's safety management system did not provide the crew with appropriate guidance in relation to the operation and maintenance of the OBA sets; and there were no

engineering controls in place to prevent the inadvertent connection of an OBA cylinder to the air compressor.

FACTUAL INFORMATION

Universal Gloria

Universal Gloria (IMO No. 9286877) is a woodchip carrier (Figure 1) that was built in 2004 by Imabari Shipbuilding, Japan. It has an overall length of 228.93 m, a beam of 35.4 m and a deadweight of 62,716 tonnes at a summer draught of 11.418 m.

The ship's six cargo holds are located forward of the accommodation and are serviced by three centreline mounted cargo cranes, discharge hoppers and conveyor belts.

Propulsive power is provided by a Mitsubishi 6UEC60LSII two-stroke, single acting, diesel

Figure 1: *Universal Gloria*



1 All times referred to in this report are local time, Coordinated Universal Time (UTC) + 11 hours.

engine. The engine drives a single, fixed pitch propeller which gives the ship a service speed of about 14 knots².

At the time of the incident, *Universal Gloria* was registered in Panama and classed with Nippon Kaiji Kyokai (ClassNK). It was owned by Manatee Navigation, Panama, operated by Kawasaki Kisen Kaisha ('K' Line), Japan, and managed by Taiyo Nippon Kisen (TNKC), Japan.

The ship had a crew of 22, comprising 19 Filipino and three Japanese nationals, all of whom were appropriately qualified to hold their positions on board the ship.

The master had 37 years of seagoing experience. He held a master's certificate of competency that was first issued in the Philippines in 2000. He had been working on board 'K' Line ships for about 16 years and had been sailing as master for about 5 years.

The chief mate had 15 years of seagoing experience, all of which was on board 'K' Line ships. He held a chief mate's certificate of competency that was issued in the Philippines and *Universal Gloria* was his first ship as chief mate.

The third mate held a third mate's certificate of competency that was issued in the Philippines. He had about 4 years of seagoing experience, the last 3 years of which had been on board 'K' Line ships. He joined *Universal Gloria* in March 2011 as an able seaman (AB) and was promoted to third mate in July 2011. This was his first assignment as third mate.

Fire fighting equipment

Universal Gloria was equipped with fixed and portable fire fighting equipment in accordance with SOLAS³ requirements.

The mandatory equipment included two Sabre self contained air breathing apparatus (BA sets) (Figure 2), four spare BA cylinders and a portable air compressor (compressor) that was used to re-fill the BA cylinders (Figure 4). The compressor was oil lubricated and its discharge tube was

fitted with a charcoal filter that prevented any contaminants or oil from carrying over with the discharge air.

In addition to the mandatory BA sets, 'K' Line had equipped the ship with four Kawasaki Safety Service⁴ (Kawasaki) OXY GEM closed circuit oxygen breathing apparatus (OBA sets) (Figure 3). Three of these sets were for operational purposes with one reserved for training and drills.

Figure 2: BA set



Figure 3: OBA set

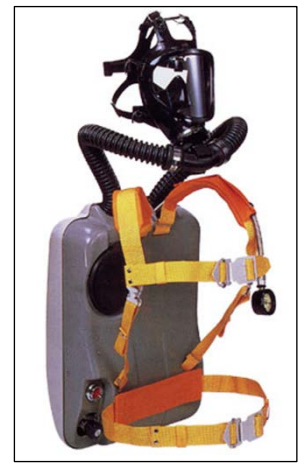
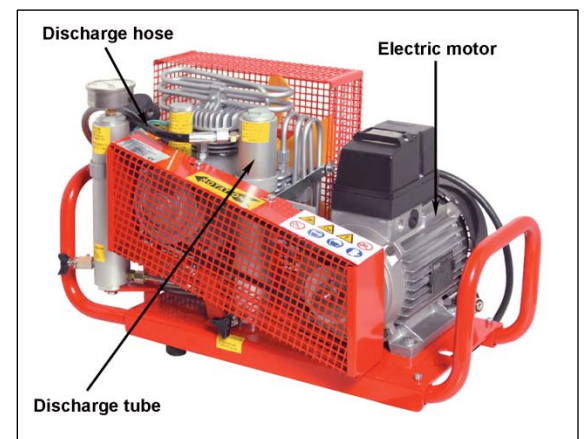


Figure 4: Similar portable air compressor



The incident

On 26 September 2011, *Universal Gloria* departed Japan, bound for Eden, Australia.

During the voyage, the crew carried on with routine watchkeeping and maintenance tasks. They also completed regular fire fighting, lifeboat and pollution response drills.

2 One knot, or one nautical mile per hour equals 1.852 km/hr.

3 The International Convention for the Safety of Life at Sea, 1974, as amended.

4 Now known as Air Water Safety Service.

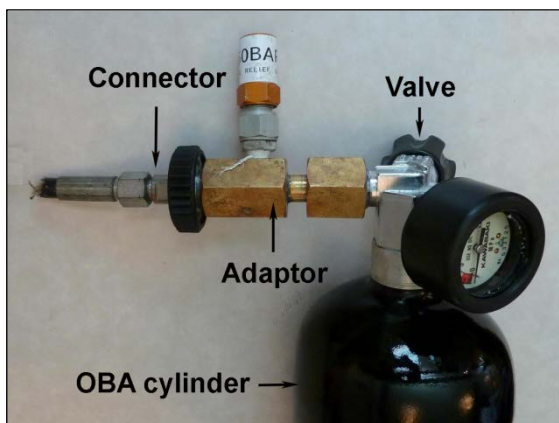
At about 0745 on 11 October, during the handover of the bridge watch, the third mate told the chief mate that he would inspect the lifesaving and fire fighting equipment before the ship arrived at Eden later that day. He also mentioned that he might need to re-fill the BA cylinders if their pressures were low. In response, the chief mate said that he would assist if the cylinders required re-filling.

At about 1200, the third mate completed his watch. He had lunch and then started his inspections. He checked the lifeboats, liferafts, lifebuoys, fire hoses and emergency batteries before going to the fire locker to inspect the equipment stored there. On the way to the fire locker, he was joined by an AB who offered to assist.

When the third mate arrived at the fire locker, he checked the pressures in the BA cylinders and found them to be satisfactory. He also checked the pressures in the OBA cylinders. The pressure in one of the OBA cylinders was about 7 MPa, well below the normal 20 MPa, so he decided to remove the cylinder and take it to the steering compartment so he could use the compressor to re-fill it.

On his way to the steering compartment, the third mate got a bucket and filled it with ice and water. He planned to place the OBA cylinder in the bucket of ice water to keep it cool while re-filling it.

Figure 5: Cylinder, hose connector and adaptor



At about 1450, the third mate and the AB arrived at the steering compartment. The third mate placed the OBA cylinder in the bucket of ice water and tried to screw the compressor discharge hose connector into the OBA cylinder, but it did not fit. He found an adaptor in the box next to the compressor that fitted both the OBA cylinder and

the compressor discharge hose connector. He fitted the adaptor to the hose connector and then fitted it to the OBA cylinder (Figure 5).

The third mate checked all the connections and opened the OBA cylinder valve. Then, as he reached over the compressor to switch it on, the compressor discharge tube (Figure 4) exploded.

The third mate was engulfed in a ball of flame. He jumped to his feet, regained his composure, and then ran out of the steering compartment.

The AB reported the fire, which continued to burn on and around the compressor, to the bridge watchkeeper. He then went to the engine room to get a portable fire extinguisher. He quickly returned with an extinguisher and discharged its contents onto the fire, extinguishing it.

Meanwhile, the third mate made his way to the ship's office, where he met the chief mate and the cadet. Shortly afterwards, the two cooks came into the office to investigate the commotion they had heard.

The third mate's overalls were removed and his injuries, burns to his face and hands, were cooled with running water and then cleaned. He was later taken to the ship's hospital where further first aid treatment was provided.

At 1545, the Eden harbour master contacted *Universal Gloria's* master by very high frequency (VHF) radio to request the ship's estimated time of arrival, draughts and security level. During the conversation, the master reported that there had been an explosion on board the ship; that the third mate had suffered serious burns; and that medical assistance was required. The harbour master asked if the third mate could be evacuated by boat or if a helicopter was required. The master advised that a boat would be sufficient. The harbour master then told the master to proceed to the anchorage and that he would arrange for medical assistance to meet the ship there.

The harbour master telephoned the ambulance service, the local water police and the ship's agent; and it was agreed that the water police would transport the paramedics to the ship when it arrived at the anchorage.

At 1705, *Universal Gloria's* starboard anchor was let go in the Eden anchorage.

At 1723, the paramedics arrived at the boat harbour. They boarded the police vessel *Falcon* and it departed for *Universal Gloria*.

At 1743, the paramedics boarded *Universal Gloria* via the ship's gangway. They were escorted to the ship's hospital where they examined the third mate and provided him with medical treatment.

The paramedics determined that, because of his injuries, it was impractical to take the third mate down the ship's gangway and onto *Falcon*, so they arranged for a helicopter medical evacuation.

At 1800, the helicopter arrived and a paramedic was winched down onto the ship's main deck. The paramedic was escorted to the ship's hospital, where he examined the third mate and discussed his condition with the other paramedics. The third mate was then assisted down to the main deck.

At 1830, the helicopter paramedic and the third mate were winched off the ship's deck. Once they were safely on board the helicopter, it departed for Canberra Hospital.

On 12 October, the third mate was transferred to Concord Hospital, Sydney, for further treatment. He remained there until 28 October, when he was discharged and repatriated to the Philippines.

ANALYSIS

The explosion

When the third mate opened the OBA cylinder outlet valve, gaseous oxygen (pressurised to about 7 MPa) flowed from the cylinder into the compressor discharge hose and tube which contained air at atmospheric pressure (0.1 MPa).

The oxygen continued to flow until the pressure inside the discharge hose and tube reached equilibrium with the pressure inside the OBA cylinder. During this process, it is likely that the temperature of the oxygen-rich environment within the discharge hose and tube dramatically increased⁵ as a result of adiabatic compression⁶.

Within seconds, the temperature of the oxygen-rich environment would have exceeded the auto ignition⁷ temperature of any oil that had been trapped in the discharge tube filter, or any other part of the discharge circuit. Once the oil ignited, a near instantaneous over-pressurisation within the compressor caused the rupture of the discharge tube (Figure 6) and hose. A flame front was then blown out of the compressor, engulfing the third mate.

Figure 6: Section of fractured discharge tube



Compressor safety devices

The compressor adaptor was fitted with a relief valve that was probably designed to control over-pressurisation of compressed air due to a closed cylinder valve or operator inattention during re-filling of a cylinder.

5 Calculations indicate that the temperature of the oxygen may have reached about 700 °C as a result of adiabatic compression alone.

6 When oxygen within a system is compressed rapidly, with no heat loss to the surrounding materials, it causes a rapid temperature rise in the gas.

7 The lowest temperature at which a material will ignite due to heat alone, without the introduction of a flame.

When the relief valve assembly was examined by the ATSB after the incident, the valve was seated in its normal resting state. There were no combustion products or other contaminants within the valve orifices or valve seat region. Hence, it is unlikely that the relief valve operated at the time of the explosion.

Had the relief valve operated, it is likely that it would have provided the compressor with little protection because it was not large enough to cope with the near instantaneous over-pressurisation that occurred inside the compressor when the oil was ignited in the oxygen-rich environment.

High pressure cylinders

There are internationally recognised colour schemes used in industry so that high pressure cylinders containing different gases can be easily identified.

There are also a number of different types of engineering controls that prevent a high pressure cylinder from being connected to an incompatible system. An oxygen/acetylene welding set is an example where such engineering controls are used. The threads on the oxygen cylinder are right handed, whereas the threads on the acetylene cylinder are left handed. Therefore, the cylinders cannot be incorrectly connected to the welding set.

All 'K' Line ships were supplied with Kawasaki OBA sets and either Sabre or Kawasaki BA sets. The cylinders used in all these sets were colour coded. The BA cylinders were pale green in colour, signifying that they contained air and the OBA cylinders were black, indicating that they contained oxygen. The OBA cylinders were also labelled 'oxygen' (in Japanese only) and stamped with the molecular formula for oxygen 'O₂'.

The Sabre cylinders had a European standard threaded connection that was different to that of the Kawasaki air and oxygen cylinders. Therefore, the Kawasaki air and oxygen cylinders could not be connected to a Sabre BA set or an air compressor fitted with a European standard connection.

The Kawasaki cylinders were manufactured to conform to the Japanese standard for high pressure gas cylinder valves. However, the threaded connections on both types of Kawasaki

cylinders were the same and there were no other engineering controls in place to prevent a Kawasaki oxygen cylinder from being connected to a Kawasaki BA set or an air compressor fitted with a Kawasaki type threaded connection.

Therefore, it was possible for a Kawasaki OBA cylinder to be inadvertently connected to an air compressor fitted with a Kawasaki type threaded connector.

Compressor discharge hose adaptor

The compressor discharge hose adaptor that allowed the connection of Kawasaki BA cylinders to the air compressor (Figure 5) was not required on board *Universal Gloria* because the ship only had Sabre BA sets. However, the adaptor had been supplied in case the ship ever carried Kawasaki BA sets.

At the time that the adaptor was supplied, there was probably no consideration of the fact that the oxygen cylinders in the Kawasaki OBA sets had the same thread as Kawasaki BA cylinders and that the adaptor would allow the inadvertent connection of an oxygen cylinder to the air compressor. As a result, the adaptor was placed in the box next to the compressor in case Kawasaki BA sets were ever carried on board the ship in the future.

Knowledge and awareness

The third mate had been sailing at that rank for about 3 months. Hence, on the morning of 11 October, when he suggested to the chief mate that he may need to re-fill the BA cylinders, the chief mate said that he would assist him. The chief mate thought that this would provide an opportunity to impart some practical training.

However, later that day, when the third mate decided to re-fill the OBA cylinder, he did not call the chief mate. He thought that the chief mate would be busy preparing for the ship's arrival at Eden and he did not want to disturb him. Furthermore, he did not think that he needed the chief mate's assistance because he had been trained in the use of BA sets while he was at college, had used BA sets during fire drills and had re-filled BA cylinders many times before.

While the third mate had some experience and training in the operation and maintenance of BA sets, he was not aware of some of the

fundamental differences between BA sets and OBA sets. He understood that the OBA sets recycled cleaned exhaled breath and provided longer operating times than conventional BA sets. However, he thought that both OBA cylinders and BA cylinders contained oxygen.

The third mate did not understand that the pale green colour of the BA cylinders signified that they were filled with air, or that the compressor would re-fill them with air. Furthermore, he did not understand that air is a mixture of 78% nitrogen, 21% oxygen and other trace gases. In fact, he thought that oxygen and air were the same thing.

Unfortunately, it was this lack of knowledge and experience that led to the third mate connecting a pressurised oxygen cylinder to an air compressor. An action that resulted in the inevitable oxygen fire within the compressor that followed.

Training

The crew on board *Universal Gloria* understood that the OBA sets had been supplied to all TNKC managed 'K' Line ships as an additional resource for fighting fires. However, they were not all familiar with the operation and maintenance requirements associated with them.

The master and the chief mate, both long term TNKC employees, understood that the OBA set cylinders contained oxygen and that they had to be sent ashore for re-filling. However, the third mate, the officer responsible for the maintenance of the ship's fire fighting equipment, was not aware of this requirement.

Although the third mate had only been sailing at that rank for 3 months, he had been working on board TNKC managed 'K' Line ships for about 3 years. Therefore, he should have had a good appreciation of the difference between BA sets and OBA sets and an understanding of their differing maintenance requirements.

Since OBA sets were not part of a ship's mandatory SOLAS fire fighting equipment, they were not covered by seafarer pre-sea training. Therefore, the responsibility for appropriately training the crew lay with *Universal Gloria*'s operators and its senior officers.

In the 7 months the third mate had been on board *Universal Gloria*, there had been no on board training in the use of the OBA sets. Furthermore,

the OBA sets had not been used by the crew during any fire drills that had been carried out in that time. In fact, the third mate could only recollect using OBA sets during one fire drill in the 3 years that he had been working on board TNKC managed 'K' Line ships.

While 'K' Line and TNKC had been proactive in providing *Universal Gloria* with equipment in excess of that required by SOLAS, they had not ensured that the ship's crew were appropriately trained and routinely drilled in the use of the equipment.

Guidance material

When the ATSB investigators were on board *Universal Gloria*, they found a copy of the OBA set operating manual in each of the OBA set storage boxes. However, a copy of the manual was not included in the SOLAS training manual, the document that was specifically on board for the induction and training of the crew.

According to SOLAS, the training manual shall contain instructions and information on the lifesaving appliances provided on board the ship and the best methods of survival. Therefore, *Universal Gloria*'s training manual should have contained information relating to the operation and maintenance of the OBA sets, even though the equipment was in excess of the SOLAS mandated equipment.

Universal Gloria's safety management system also contained an on board fire fighting manual. This manual contained some basic information regarding the differences between BA sets and OBA sets. However, it contained no information regarding the operation and maintenance of the OBA sets. Furthermore, the document referred exclusively to fire fighting in the vehicle decks of car carriers, information that was of little use to the crew on board *Universal Gloria*, a woodchip carrier.

Previous oxygen system fires

Despite high pressure oxygen systems being designed with consideration of the properties of gaseous oxygen, there have still been a number of recorded oxygen system fires.

Two such incidents have been investigated by the Australian Transport Safety Bureau (ATSB) and its

aviation predecessor, the Bureau of Air Safety Investigation (BASI).

In 2006, a ship's crew member was seriously burned when a nylon lined flexible hose connected to a welding set oxygen cylinder ruptured as a result of adiabatic compression.⁸

In 1997, a Bell helicopter was destroyed following an oxygen system fire. In this case, either particle impact or adiabatic compression ignited the polyester lining of a flexible hose that had been fitted to the system.⁹

FINDINGS

Context

From the evidence available, the following findings are made with respect to the serious burns that the third mate suffered as a result of the explosion that occurred on board *Universal Gloria* on 11 October 2011 when he attempted to use an air compressor to re-fill an oxygen cylinder. They should not be read as apportioning blame or liability to any particular organisation or individual.

Contributing safety factors

- The compressor discharge tube and hose ruptured due to an over-pressurisation that occurred when oil ignited in the hot oxygen-rich environment within the discharge circuit of the compressor.
- The third mate did not possess sufficient knowledge to enable him to safely and effectively operate and maintain the ship's oxygen breathing apparatus.
- The ship's safety management system documentation did not provide the crew with appropriate guidance in relation to the operation and maintenance of the oxygen breathing apparatus. [*Minor safety issue*]
- The ship's crew were not appropriately trained or drilled in the operation and maintenance of the oxygen breathing apparatus. [*Minor safety issue*]

- The threaded connections on the Kawasaki air breathing apparatus and oxygen breathing apparatus cylinders were the same and there were no other engineering controls to prevent an oxygen cylinder from being connected to the air compressor. [*Minor safety issue*]
- The adaptor that enabled the connection of Kawasaki breathing apparatus air cylinders to the air compressor was not required on board the ship. However, it had been left with the air compressor and, as a result, could be used for purposes other than the one that it was designed for.

Other key finding

- The ship's fire fighting manual referred exclusively to fire fighting in the vehicle decks of a car carrier and, hence, was of little assistance to the crew on board a woodchip carrier.

SAFETY ACTION

The safety issues identified during this investigation are listed in the Findings and Safety Actions sections of this report. The Australian Transport Safety Bureau (ATSB) expects that all safety issues identified by the investigation should be addressed by the relevant organisation(s). In addressing those issues, the ATSB prefers to encourage relevant organisation(s) to proactively initiate safety action, rather than to issue formal safety recommendations or safety advisory notices.

All of the responsible organisations for the safety issues identified during this investigation were given a draft report and invited to provide submissions. As part of that process, each organisation was asked to communicate what safety actions, if any, they had carried out or were planning to carry out in relation to each safety issue relevant to their organisation.

Taiyo Nippon Kisen

Documentation

Minor safety issue

The ship's safety management system documentation provided the crew with no guidance in relation to the operation and maintenance of the oxygen breathing apparatus.

⁸ ATSB Marine Investigation Report No. 233 which can be downloaded from the website www.atsb.gov.au.

⁹ BASI Aviation Investigation Report No. 9701421 which can be downloaded from the website www.atsb.gov.au.

Action taken by Taiyo Nippon Kisen

The company has not advised the ATSB of any actions that have been taken to address this safety issue.

Training

Minor safety Issue

The ship's crew were not appropriately trained or drilled in the operation and maintenance of the oxygen breathing apparatus.

Action taken by Taiyo Nippon Kisen

The company has advised the ATSB that they have forwarded a safety bulletin to all of its managed ships highlighting the lessons that can be learnt from the incident. These include the need to;

- re-fill all OBA oxygen cylinders ashore;
- clearly mark the word 'oxygen' in English on all OBA oxygen cylinders;
- post signs on all breathing apparatus compressors stating that they are only to be used to re-fill air breathing apparatus and emergency escape breathing device cylinders;
- seek approval from a responsible person prior to re-filling cylinders; and
- assign more than one crew member to the task of re-filling cylinders.

ATSB assessment of action

The ATSB considers that the action taken by Taiyo Nippon Kisen addresses this safety issue.

Air Water Safety Service

High pressure cylinders

Minor safety Issue

The threaded connections on the Kawasaki air breathing apparatus and oxygen breathing apparatus cylinders were the same and there were no other engineering controls to prevent an oxygen cylinder from being connected to the air compressor.

Action taken by Air Water Safety Service

The company has advised the ATSB that it will place caution labels on all future oxygen cylinders. These labels will draw attention to the fact that the re-filling and inspection of the cylinders must

be carried out ashore; and that the cylinders should only ever be re-filled with oxygen.

ATSB assessment of action

The ATSB considers that the action taken by Air Water Safety Service addresses this safety issue.

SOURCES AND SUBMISSIONS

Sources of Information

Universal Gloria's master and crew

NSW Maritime

NSW Water Police

Ambulance Service of NSW

Taiyo Nippon Kisen

References

International Maritime Organization. Safety of Life at Sea Convention (SOLAS). Consolidated edition, London, 2009.

Submissions

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

A draft of this report was provided to *Universal Gloria's* master, chief mate and third mate, Taiyo Nippon Kisen, Air Water Safety Service, the Eden harbour master, the Australian Maritime Safety Authority (AMSA) and the Panama Maritime Authority.

Submissions were received from *Universal Gloria's* master and chief mate, Taiyo Nippon Kisen, Air Water Safety Service, the Eden harbour master and the Australian Maritime Safety Authority (AMSA). The submissions were reviewed and where considered appropriate, the text of the report was amended accordingly.