



Australian Government
Australian Transport Safety Bureau

Loss of propulsion on passenger cruise ship *Norwegian Star*

Bass Strait, 22 NM SW of Cape Liptrap, Victoria | 10 February 2017



Investigation

ATSB Transport Safety Report
Marine Occurrence Investigation
MO-2017-003
Final – 24 May 2018

Cover photo: Norwegian Cruise Line Holdings

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Addendum

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Safety summary

What happened

On 9 February 2017, the passenger cruise ship *Norwegian Star* departed Melbourne, Australia, on a scheduled cruise to Dunedin, New Zealand. There were 2,113 passengers and 1,017 crew on board. On departure, the starboard propulsion unit was operational following its recent repair, and the port propulsion unit was under repair following its failure on 24 January. This meant that the ship was operating only with the starboard propulsor.

At about 0134 on 10 February, *Norwegian Star* was about 22 NM south-west of Cape Liptrap, Victoria, Australia, when the starboard propulsion unit failed. Propulsion could not be restored and tugs were deployed from Melbourne to tow the ship back to Melbourne. The ship arrived back without further incident at about midnight on 11 February.

What the ATSB found

The ATSB found that *Norwegian Star* lost function of its starboard propulsion as a result of the failure of the recently repaired starboard exciter. The configuration of the exciter unit had been modified as part of its repair, and the unit failed as a result of an error in the design of the modification. Insufficient clearance had been provided to allow for movement and thermal expansion of components during the unit's operation. This error was not detected during the design, installation and trialling of the modified exciter unit.

The need for the repair of the starboard exciter unit had followed its failure on 11 December 2016. The failure of the unit in its original (as-built) configuration, and the subsequent failure of the original port exciter unit on 24 January, were both probably due to a breakdown in electrical insulation. Processes for the monitoring of exciter unit condition were ineffective in detecting deterioration prior to unit failure.

The ship operator's decision to sail from Melbourne with only the starboard propulsion unit did not breach any regulatory requirement and was based on confidence in the reliability of the repaired starboard unit. While the repaired exciter was of proven design concept, the detailed design specific to this propulsion system application had not previously been used in-service.

What's been done as a result

The ATSB has issued recommendations to the ship operator Norwegian Cruise Line Holdings and the equipment manufacturer ABB Industry Oy to review the processes for monitoring the condition of brushless exciter units in Azipod installations, considering the mechanism of failure of the port and starboard brushless exciter units on *Norwegian Star*.

Safety message

Operation of newly designed equipment without redundancy increases operational risks. Equipment manufacturers and ship operators must apply extra diligence when designing, installing and operating modified equipment, especially safety critical equipment.

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The occurrence

Norwegian Star

Norwegian Star was scheduled to cruise South-East Asia towards the end of 2016, moving to the Oceania region in January 2017, and then cruising East Asia from March 2017.

The *Norwegian Star* was fitted with two electric driven, podded propulsion units¹ (Azipod)² giving it a maximum speed of about 25 knots.³

Prior to arriving in Melbourne

On 11 December 2016, *Norwegian Star* (cover photo) was preparing to depart Singapore when the starboard propulsion unit circuit breaker tripped, with the alarm panel indicating an 'overcurrent earth failure'. Inspection of the exciter unit for the starboard propulsion motor found evidence of flashover marks on the stator winding.

Repair of this exciter unit to its existing configuration would require the ship to be taken out of service. Instead, it was decided to modify the starboard exciter unit from the brushless system to a slipring and brush system. This modification and repair could be done without taking the ship out of service.

While the starboard exciter unit was being repaired, *Norwegian Star* was capable of operating with one propulsion unit but at a reduced maximum speed of between 13 and 16 knots. The ship's schedule was amended to allow for the reduced speed and approvals were granted by relevant authorities for the ship to continue in service.

Repair was ongoing whilst the ship continued a program of cruises between Singapore and Hong Kong using its port Azipod. The installation of the modified starboard exciter unit was completed on 14 January 2017 and tested at full load between 14 and 20 January. The starboard Azipod was tested and passed by the Classification Society⁴ on 20 January 2017 in Singapore.

On 22 January 2017, *Norwegian Star* resumed normal operations with both propulsion units operational, departing Singapore for Darwin, Australia, stopping in Indonesia. Then, on 24 January 2017, the port Azipod exciter unit failed. The failure of the port unit appeared similar to that of the starboard unit in December and would also require repair.

The ship was now operating solely with the modified starboard propulsion unit and arrived in Darwin on 29 January 2017. The ship departed Darwin and called at Cairns and Sydney before arriving in Melbourne on 8 February 2017. In Melbourne, technicians from the Azipod manufacturer were on board to repair the port exciter unit using the same modification as had been made to the starboard unit. This repair had not been completed when the ship departed Melbourne.

¹ An electric propulsion system located in a submerged pod that could be rotated 360 degrees around its vertical axis.

² Azipod is the registered trademark of ABB Industry Oy (Finland).

³ One knot, or one nautical mile per hour, equals 1.852 kilometres per hour.

⁴ The role of the Classification Society can be found on page 8 of this report

The incident

Norwegian Star departed Melbourne on the evening of 9 February 2017 bound for Dunedin, New Zealand with 2,113 passengers and 1,017 crew. The ship exited Port Phillip Heads (the Heads) at 2118⁵ and at 2133 dropped off the pilot and proceeded into Bass Strait (Figure 1).

At 0134 on 10 February 2017, *Norwegian Star* was about 22 NM south-west of Cape Liptrap⁶ (on the south coast of Victoria) when the starboard propulsion unit failed. Inspection found arcing and pitting damage on the outer slipring of the modified exciter unit, and propulsion could not be restored.

Norwegian Star was disabled and drifting in an approximately north-north-easterly direction in about 75 m depth of water. The wind at that time was from the south-east at about 5 knots, the sea condition was slight and the swell about one metre from the south-west. The current was negligible. The ship's bow thrusters were used to manoeuvre the ship's head into the wind, reducing the rate of drift to about one knot.

The recovery

The owners and relevant shore authorities were informed and arrangements made to deploy tugs to tow the ship back to Melbourne. The Australian Maritime Safety Authority (AMSA) coordinated the recovery operation.

Drift modelling predicted that the earliest the ship might run aground was at about 0630 on 11 February near Cape Liptrap. The ship made contingency arrangements to anchor when the depth of water reduced to 50 m at which point the ship would be about 5 NM from the nearest land.

At about 1957 on 10 February, the tug *Hastings* (50 tonnes bollard pull, 473 gross tonnage) arrived and at about 2048 the tow line was connected. At 2121 *Hastings* commenced towing *Norwegian Star* towards Port Phillip Heads at a speed of about 4.5 knots. The tug *Tom Tough* (46 tonnes bollard pull, 396 gross tonnage) arrived at 2212 and accompanied the tow.

At about 1107 on 11 February 2017, *Tom Tough* was made fast to the stern and the speed of the tow reduced. At about 1338 *Norwegian Star* arrived at the pilot boarding ground and two pilots boarded the ship.

Norwegian Star entered Port Phillip Heads at about 1506, at a speed of about 4 knots. The tide was at slack water. At 1528, a third tug, *Svitzer Marysville* (68 tonnes bollard pull, 250 gross tonnage), was made fast on the port quarter to assist with manoeuvring the ship. The tow then continued in Port Phillip Bay without incident and the ship was berthed at Station Pier at about 2358.

Resumption of cruise operations

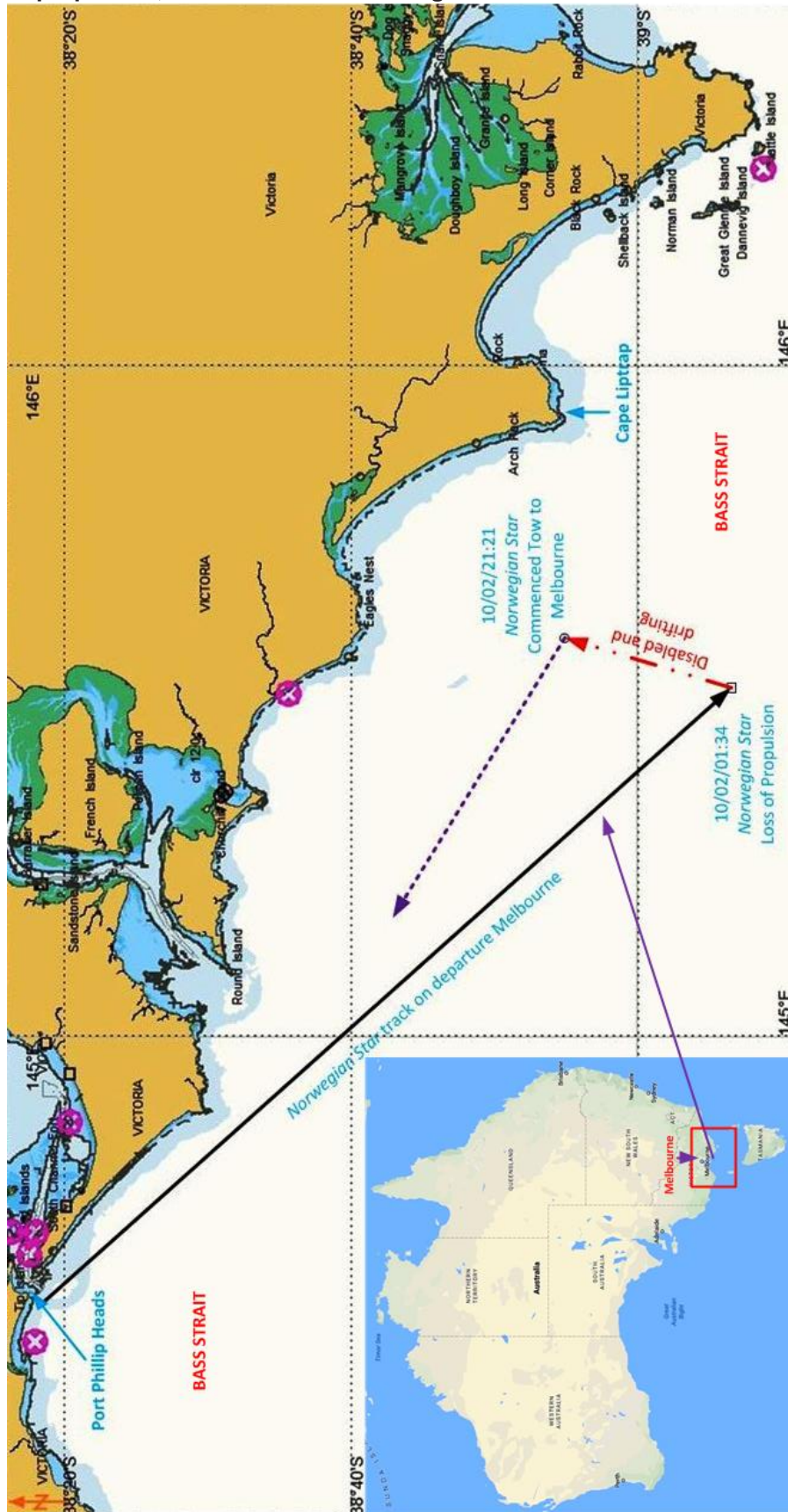
The ship remained in Melbourne while both the port and starboard exciter units were repaired, incorporating modifications to the slipring and brush exciter.

Both propulsion units were commissioned and after a series of sea trials within Port Phillip Bay, detention notices were revoked by Port State Control, permitting the ship to resume its voyage. *Norwegian Star* departed Melbourne for New Zealand on 14 February.

⁵ All times referred to in this report are local time, Coordinated Universal Time (UTC) + 11 hours.

⁶ Latitude 39° 06.8' S Longitude 145° 31.8' E.

Figure 1: The track of *Norwegian Star* from Port Phillip Bay until its loss of propulsion, and its drift before being towed back to Melbourne



Source: Australian Hydrographic Office ENC Charts AU 439144 and 439145 [Inset: Google Map of Australia], with annotations by Chief Investigator, Transport Safety

Context

The operator

At the time of the incident, *Norwegian Star* was owned and operated by Norwegian Cruise Line Holdings Ltd (NCLH), headquartered in Miami, Florida, United States of America. The company began operations in 1966 under the name Norwegian Caribbean Line and in 1987 changed to its current name. NCLH operated a fleet of 15 passenger ships and provided passenger cruises throughout the world.

Norwegian Star

Norwegian Star was built in November 2001 at the Meyer Werft shipyard in Papenburg, Germany. It was built in accordance with the DNV⁷ Rules for Ships, and complied with the requirements of SOLAS⁸ for structural design, navigational equipment and machinery installations. The ship was registered in the Bahamas and classed⁹ with DNV GL.¹⁰

Norwegian Star has a gross tonnage of 91,740, an overall length of 294.13 m, maximum breadth of 38.10 m and a summer draft of 8.60 m. Electric power, including for ship propulsion, was supplied by four diesel generators providing a total output of 58,800 kW.

The propulsion system consisted of two¹¹ independent electric-driven 5-bladed ABB V02300 Azipods. Each unit delivered 19,500 kW of propulsion power at 137 rpm for a maximum ship speed of about 25 knots. The ship was also fitted with three bow thrusters, having a total output of 7,080 kW.

The ship's certification was current and all crew were appropriately qualified for the positions they held.

Propulsion

NCLH fleet installations

Ten of the 15 ships in the NCLH fleet were fitted with Azipod propulsion systems, with *Norwegian Star* having the fleet's oldest Azipod installation.

Azipod

Norwegian Star was fitted with two Azipods, mounted port and starboard near the stern. The ship could be propelled using either Azipod or both combined. Each Azipod was independent of the other's operation, and complied with SOLAS and classification society requirements for propulsion and steering. At sea, the propulsion units were normally operated concurrently.

Azipod propulsion is a gearless, steerable propulsion system with the electric motor installed in a submerged pod beneath the ship's hull. The Azipod can be rotated through 360 degrees, removing the need for a rudder. On the *Norwegian Star*, propellers were fixed pitch mounted face forward, in a pulling configuration (Figure 2).

⁷ Det Norske Veritas.

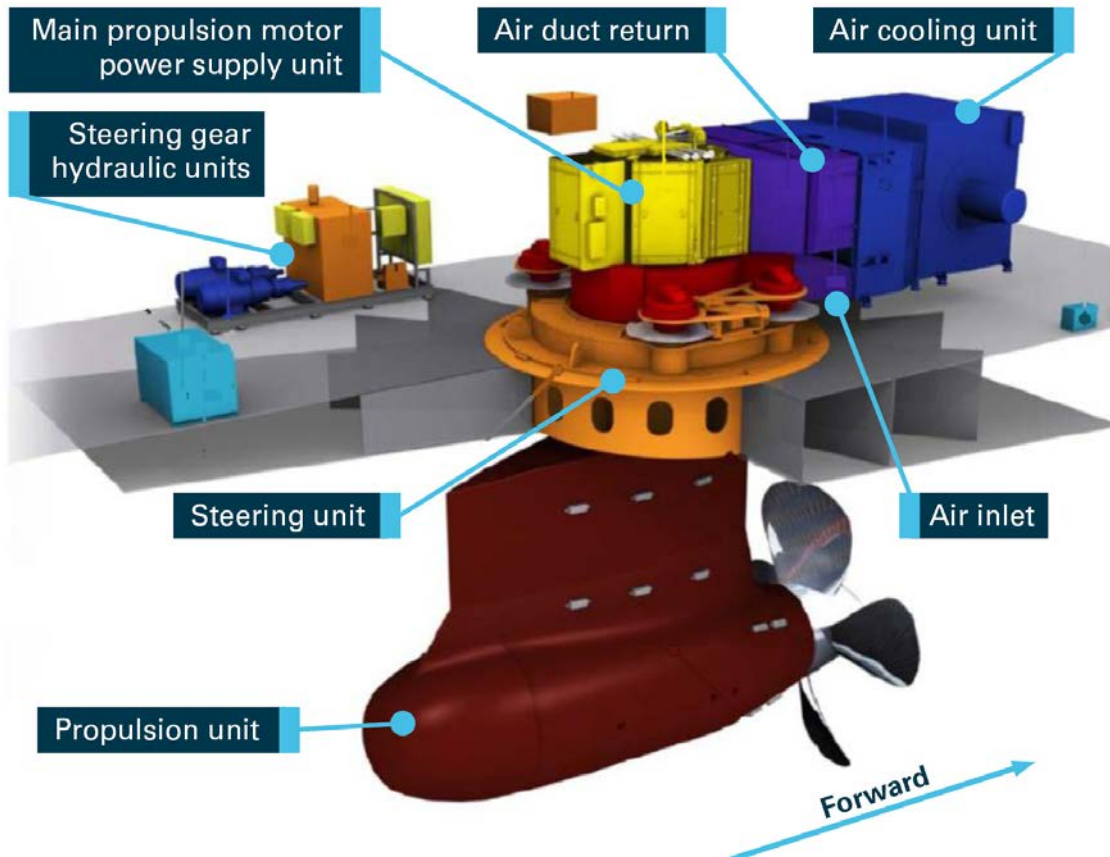
⁸ The International Convention for the Safety of Life at Sea 1974, as amended.

⁹ A ship that has been designed and built to the appropriate Rules of a classification society may apply for a certificate of classification from that society.

¹⁰ Classification societies Det Norske Veritas and Germanischer Lloyd merged in 2013 and became DNV GL.

¹¹ When propulsion is provided by thrusters only, there are normally to be at least 2 separate thruster units. Ref: DNV Rules for Classification of Ships 1997 Pt.4, Ch.2, Sec.8C, paragraph 201.

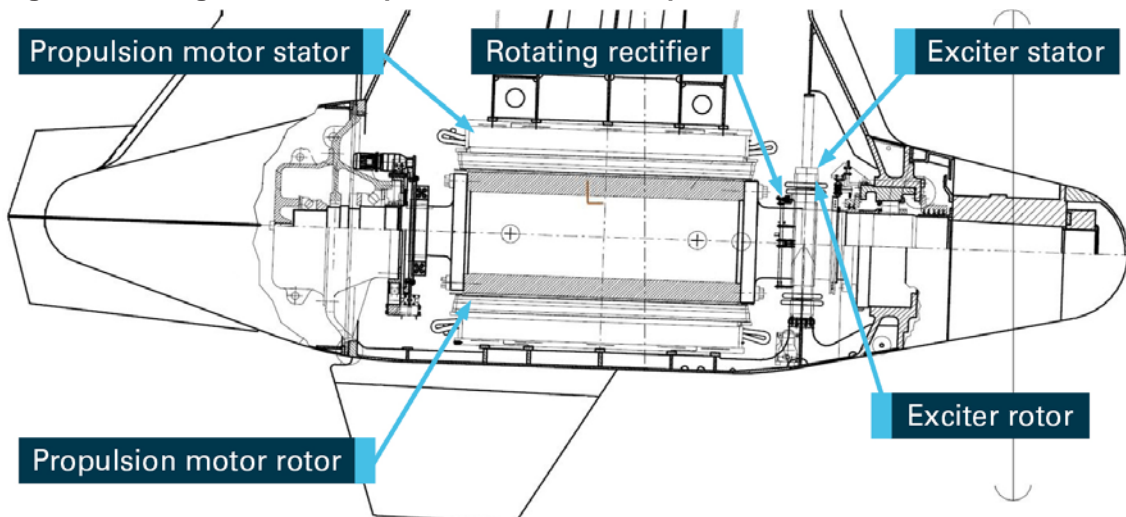
Figure 2: Azipod installation



Source: ABB Industry Oy with annotations by Chief Investigator, Transport Safety

Within the submerged pod, key components included the propulsion motor and the exciter unit (Figure 3).

Figure 3: Arrangement of components within the Azipod



Source: ABB Industry Oy with annotations by Chief Investigator, Transport Safety

Propulsion motor and excitation

The propulsion motors were of synchronous¹² type mounted on the same shaft as the propeller. The propeller speed was controlled by varying the motor speed. This was achieved by varying frequency of the motor stator supply. To ensure the motor operated at maximum efficiency, the rotor magnetic field was also varied with the motor speed. A much smaller AC generator (exciter) of 135 kW was mounted co-axially adjacent to the motor, and this provided the field excitation for the synchronous motor through a rotating rectifier (Figure 3). The exciter was brushless, and varying the exciter stator voltage provided control of its rotor voltage and hence the excitation for the motor's magnetic field. Varying excitation provided the opportunity to optimise the efficiency of the synchronous motor. The advantages of a separate machine providing brushless excitation included reduced maintenance and lower power requirements for motor field control.

Azipod inspection and maintenance

Shipboard maintenance of Azipod equipment was generally carried out when the ship was in port due to restrictions accessing the pod during ship operation.

The ship's crew undertook a series of regular checks, testing and maintenance of the propulsion systems. These tasks included monitoring bearing vibration, metal scanning of bearing lubrication oil, analysis of oil for water contamination, propeller and thrust bearing filter checks and checking of Azipod electrical and automation systems. Bearing lubrication oil filters were changed every six months. The recorded shipboard maintenance also indicates a fortnightly check of the propulsion system logs and a monthly switchover of the exciter encoder switch.

Due to the specialist nature of the propulsion equipment, part of the inspection and maintenance was undertaken by the equipment manufacturer, ABB Industry Oy (ABB). Insulation resistance of the exciter units was measured at 12 monthly intervals at the same time as the main propulsion motors. Between 26 and 30 August 2016, exciter units were inspected and insulation resistance tested, without any defects or deficiencies identified. During these inspections it was also noted that pod interiors were clean and dry. ABB also conducted acoustic emission measurements of slew bearings, borescope inspections and vibration analysis of Azipod shaft line bearings. All readings were within design limits.

The ship inspection records did not identify any deficiencies or defects with the Azipod units in the lead up to the starboard exciter failure on 11 December 2016. NCLH also reported that the exciters were classed as 'ship's life' and had not been subjected to any major maintenance work since their installation.

Conversion from brushless to slipring exciter

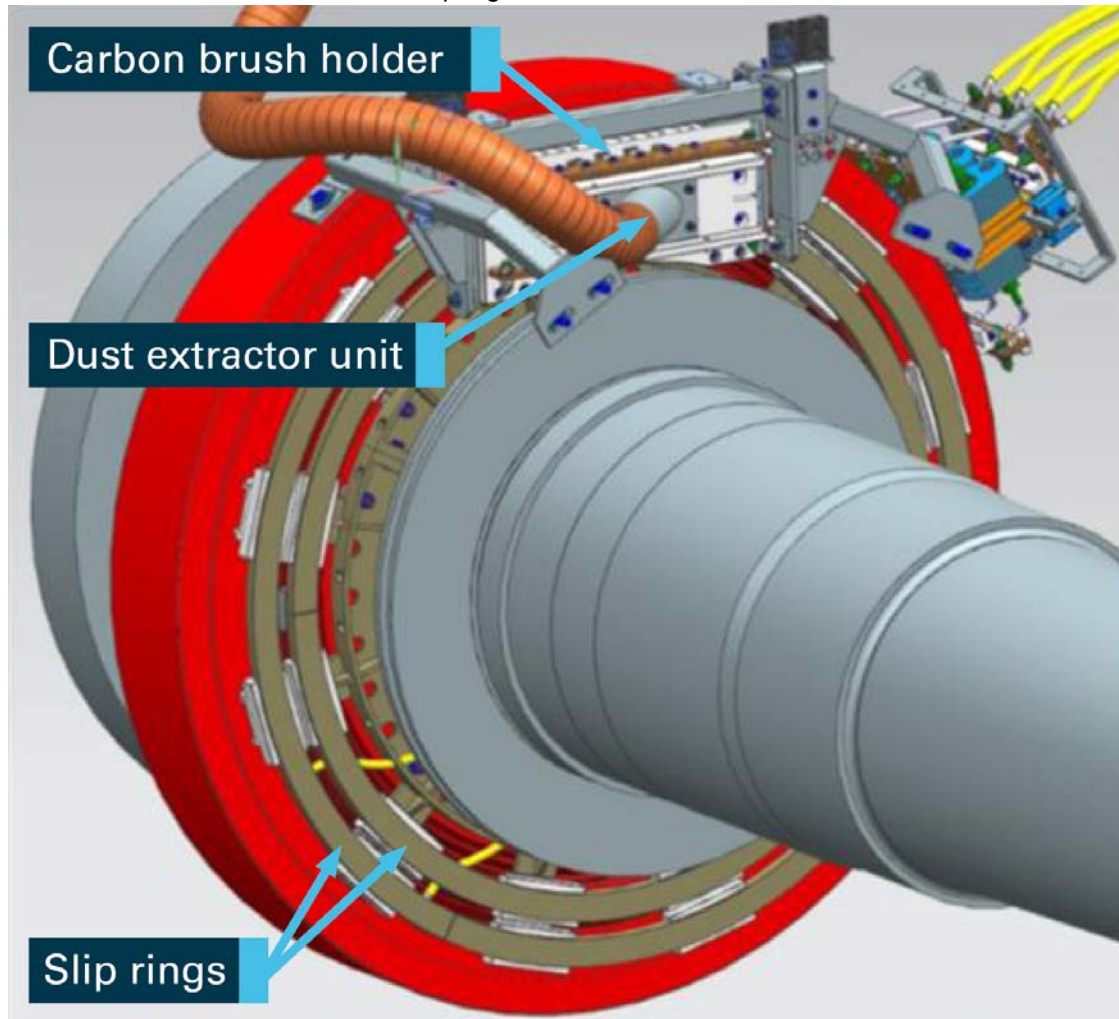
Modification

When the brushless starboard exciter unit failed on 11 December 2016, NCLH (in consultation with ABB) decided to repair the unit by modifying it from a brushless system to a slipring unit with brushes. The modification to a slipring unit involved the installation of two concentrically mounted sliprings on the existing exciter rotor, and diode bridge assemblies, carbon brush assembly and dust removal unit mounted on the stator hub assembly (Figure 4). The effect of the modification was to bypass the defective exciter and supply the field of the synchronous motor directly from a new external variable DC supply.

¹² The rotor rotates in synchronism with the stator magnetic field and supply frequency.

Figure 4: Modified starboard exciter unit with sliprings and brushes

Modified starboard exciter unit with sliprings and brushes



Source: ABB Industry Oy with annotations by Chief Investigator, Transport Safety

Justification for modification

Repair of the exciter unit to the modified design could be achieved with the ship remaining in service, whereas repairing the unit to its original brushless configuration would require the *Norwegian Star* to be removed from service.

ABB had already undertaken preparatory, ship non-specific, design work for the modification should it be required. As a result, the design modification could be quickly rolled out for ship-specific implementation. This type of modification had not previously been used on an Azipod, but had been fitted to Fixipod¹³ type propulsion systems.

Preparatory design

ABB commenced a project for emergency exciter modification for Azipods on 8 September 2016, and this was completed on 2 December 2016. ABB reported that at that time there was no target ship for installation.

¹³ An ABB podded propulsion system on a fixed vertical axis.

Design modification for Norwegian Star

For application on *Norwegian Star* following the failure of the starboard unit, the pre-approved generic modification drawings were updated specific to *Norwegian Star* and approved for installation on 23 December 2016.

ABB had documented processes for design, review and approval of technical documentation. The modification was signed-off in line with these procedural steps.

ABB advised that the configuration could be used for an unlimited period of time, although maintenance would be more demanding. Because of this higher maintenance, ABB had recommended reinstalling the original brushless arrangement at the ship's next dry docking.

DNV GL

The Classification Society

DNV GL is an international accredited classification society headquartered in Oslo, Norway. It was created in 2013 from a merger between Det Norske Veritas (Norway) and Germanischer Lloyd (Germany).

DNV GL rules are independent standards that consist of technical and procedural requirements adopted by the Society as the basis for classification of ships and offshore structures. Classification is a service which comprises the development and maintenance of Rules, and the verification of compliance with the Rules throughout a vessel's life. A certificate of classification is issued to confirm compliance with the Society's Rules as applicable at the time of survey.

Permission to sail with one propulsion unit

Following first failure

After the first (starboard) Azipod failure on *Norwegian Star* in December 2016, NCLH provided DNV GL with documentation (prepared by ABB) confirming that the ship had full manoeuvrability with only the port propulsion unit operating, and a reduced maximum speed.

DNV GL satisfied themselves that the port Azipod was fully functional in accordance with SOLAS and Class requirements and permission was granted to operate with one propulsion unit. In conjunction with this approval, DNV GL imposed a Condition of Class for the starboard Azipod to be returned to operational status by 31 January 2017.

Following second failure

When the port Azipod subsequently failed in January, DNV GL were satisfied that the modified starboard Azipod was capable of providing full manoeuvrability to *Norwegian Star*. Permission for *Norwegian Star* to continue operating with just the starboard Azipod was granted and a Condition of Class was again imposed, to have the port exciter unit operational by 31 March 2017.

Exciter unit modification

DNV GL advised that they were required to be informed of the modification to the exciter unit, and performance was to be verified by testing after installation.

Accordingly, NCLH provided DNV GL with the exciter modification drawings and the performance of the modified unit would be tested. DNV GL was satisfied with the manufacturer's assurances that the modifications were a proven and used method to excite a motor. The earlier imposed Condition of Class (following the starboard unit failure in December) was removed after the modified starboard Azipod was tested at full load.

Bahamas Maritime Authority

The Bahamas Maritime Authority (BMA) is an agency that registers ships under the Bahamas Ship Register. The function of the Authority is to enforce ship safety requirements to ensure that ships under the Bahamian flag comply with international standards as prescribed by the International Maritime Organisation (IMO). Over 50 million Gross Tonnes of shipping flies the Bahamas flag.

The BMA had no objection to *Norwegian Star* operating with one Azipod while the other was being repaired, provided that the ship could manoeuvre and go astern utilising one Azipod only and subject to the special conditions outlined by DNV GL.

Port State Control

Port State Control (PSC) is an internationally agreed regime for the inspection of foreign ships in other national ports. The remit of these officers is to investigate compliance with the requirements of international conventions of the IMO (for example, SOLAS). Inspections can involve checking that the ship is manned and operated in compliance with applicable international law, and verifying the competency of the ship's master and officers, and the ship's condition and equipment. PSC has the authority to detain a ship until it is satisfied that the ship is in a seaworthy condition and complies with the requirements of the applicable international conventions.

PSC inspections at Singapore and Hong Kong did not record any deficiencies against *Norwegian Star* sailing with only one operational propulsion unit, other than PSC Hong Kong advising that DNV GL should inform the Flag State.

The Australian Maritime Safety Authority (AMSA) is responsible for PSC in Australia. *Norwegian Star* was inspected by AMSA on 6 February when it berthed in Sydney. AMSA did not find anything to suggest the ship was unseaworthy. It was noted that the ship could maintain a speed of at least 12 knots with one propulsion unit running and maintain safe steering and navigation. AMSA was satisfied that a Condition of Class was issued to rectify the failed port propulsion unit by the end of March 2017 and that the Flag State had no objection to *Norwegian Star* operating with one Azipod.

AMSA conducted another PSC inspection when the ship berthed in Melbourne on 9 February. Six minor deficiencies were noted, one of which was that the voyage plan did not document that operating on one Azipod affected ship speed. All six deficiencies were rectified to the satisfaction of AMSA prior to the ship's departure on 9 February.

When *Norwegian Star* was towed back to Melbourne, AMSA issued a Detention Notice on the ship. The Notice was revoked once both Azipods had again been repaired and had passed sea trials.

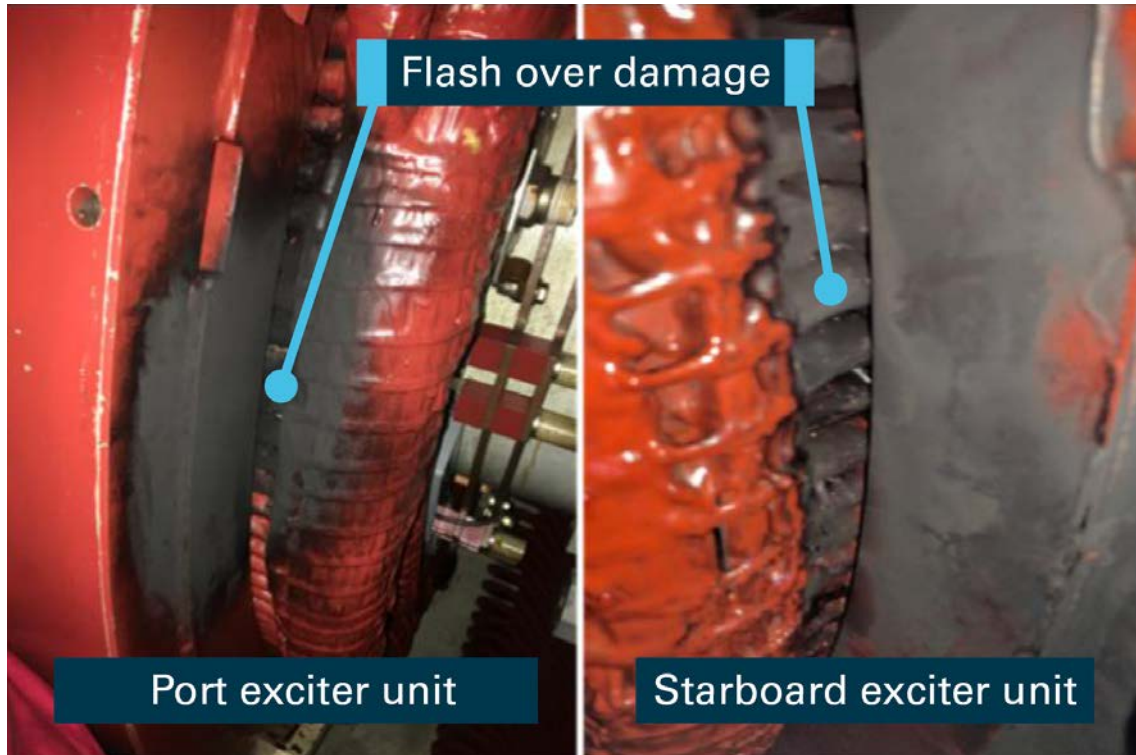
Safety analysis

Brushless exciter units

Failure

Inspection of the starboard and port exciter units after their first-time failures (on 11 December 2016 and 24 January 2017 respectively) found evidence of flashover marks on the stator windings in both units (Figure 5), suggesting a similar cause of the flashover and failure.

Figure 5: Flashover damage from the port and starboard exciter units



Source: NCLH with annotations by Chief Investigator, Transport Safety

There are a number of factors that can lead to flashover, including insulation breakdown and insulation damage as a result of bearing failure. Post-incident inspection by Norwegian Cruise Line Holdings Ltd (NCLH) found no evidence of bearing failure and therefore this has been discounted as a possible failure mechanism.

A reduction in the effectiveness of the electrical insulation on stator or rotor windings can result from age, heat, moisture, accumulation of dust and dirt or component stress due to excessive voltage. The auxiliary systems installed on *Norwegian Star* to mitigate the risk of insulation deterioration included ventilation, cooling, space heating and dust extractor systems. They were reportedly operating satisfactorily and routine inspections did not identify any deficiencies with the equipment. Therefore, there was no evidence to indicate that a defect in these auxiliary systems contributed to the exciter unit failures.

Following the flashover incidents on *Norwegian Star*, NCLH inspected the exciter units on other Azipod installations within their fleet and found surface cracks on the stator insulation on several units. ABB Industry Oy (ABB) expressed the view that these cracks were only in the surface lacquer and so should not compromise electrical insulation.

NCLH advised that further examination of the failed components cannot take place until removal of the units during ship dry docking. Closer examination of the units at that time may provide additional information on the failure mechanism. However, at the time of reporting neither NCLH nor the equipment manufacturer (ABB) has identified the mechanism of failure of the brushless units.

Based on the evidence available, deterioration of the insulation material remains the most probable cause of the failures of the brushless exciter units. *Norwegian Star's* Azipods were the oldest in the fleet and had the highest running hours. Age, heat, moisture and contamination are all possible factors that may have contributed to this deterioration.

Monitoring of insulation resistance

Norwegian Star's planned maintenance system included periodic inspection, testing and maintenance of the Azipod and its auxiliary systems by the ship's crew and the equipment manufacturer. The manufacturer's maintenance instructions for the exciter units included the annual measurement of the insulation resistance of the exciter rotor and the stator (500 V DC megger).¹⁴ The most recent annual assessment of the exciter insulation was in August 2016 with results indicating satisfactory insulation.

Notwithstanding this insulation monitoring regime, both Azipod exciter units experienced a flashover failure that was probably the result of a breakdown in electrical insulation. The regime for monitoring exciter condition was therefore ineffective for exciter units of this type, age, running hours and operating environment.

Check of port unit following failure of starboard unit

After the starboard exciter unit failure on 11 December, *Norwegian Star* remained in port for two days while a suitable repair was arranged and Flag State and classification society permission to sail with one Azipod was obtained. It was reported that neither the ship's engineers nor the manufacturer's representatives could ascertain the cause of the flashover immediately after its failure, and an investigation was commenced by ABB.

NCLH reported that the port exciter was inspected by the on-board staff after the failure of the starboard exciter unit. However, no insulation resistance measurements were taken of this unit at the time of the inspection and so an opportunity to identify possible deterioration in insulation was lost. This decision may have been influenced by the expectation of high reliability of these units based on previous experience.

Modified exciter unit

Failure mechanism

On 10 February 2017 while *Norwegian Star* was transiting Bass Strait, the modified exciter unit installed on the starboard propulsion unit failed, rendering the ship without propulsion. Pitting on the outer slipring was observed (Figure 6). Brush holders were also damaged (Figure 7).

¹⁴ ABB Synchronous machine AMZ 1400ZM12 LAEZ Users manual.

Figure 6: Arcing damage on the outer slipring



Source: ABB Industry Oy with annotations by Chief Investigator, Transport Safety

Figure 7: Arcing damage to brush holders



Source: ABB Industry Oy with annotations by Chief Investigator, Transport Safety

Detailed examination and assessment by ABB found that the damage to and failure of the unit was the result of insufficient clearance between the brush holder and sliprings. It was identified that axial movement and thermal expansion of components was more than had been allowed for in the design.

Design error

It was identified by ABB that there was an error made in the design of the modified exciter unit that was not identified during the design review process. Clearance between the brush holders and the sliprings was less than required to accommodate the axial movement and thermal expansion of components.

Process

ABB advised that a slipring type unit had not been used with the Azipod configuration before, but had been used on their Fixipod propulsion units.

A project to design a modification to their Azipod exciter units was initiated in September 2016. The material developed during this project was used as the basis for the ship-specific application on *Norwegian Star*. ABB did not provide the reasons for initiating this project.

ABB's internal quality management system provided for the processing of technical documents through several stages including design, review and approval. Documents received from ABB indicate that they complied with their quality management system. However, the error in the clearance between sliprings and brush holders was not identified during the review and approval stages of the design development.

Post-installation testing and monitoring

ABB's maintenance instructions for the modified slipring and brush exciter unit specified fortnightly visual inspections that included:

- cleaning of carbon dust and other contaminants
- ensuring that the carbon brushes were free to move within their holders
- measuring brush wear.

The modified starboard exciter was inspected on 29 January 2018 and again on 05 February 2018. During inspections, surface grooving, carbon dust and an oil film forming a 'carbon grease' were observed on the sliprings. Actions were initiated to improve dust extraction, but the cause of the grooving was not investigated further. It is probable that the grooving was the result of contact between brush holder and slipring, and an indicator of the inadequate clearance provided in the design.

Classification society approval

DNV GL's design and installation approval processes for conversions, modifications or alterations of equipment on ships is governed by internal policies and processes that are developed to align with international statutory regulations, conventions and codes. The DNV GL rules specified that some modifications were subject to classification society approval and others were not subject to such approval. Modifications not normally subject to approval but considered to affect safety or main functions were to be considered case-by-case.

DNV GL advised that the design of an excitation system was not subject to any separate requirements, approval or certification and was covered under the certification of the complete electrical machine. The classification society was to be informed of any intended modifications.

Consistent with these provisions, when the brushless starboard exciter failed and the decision was made to replace it with the slipring type, NCLH provided DNV GL the design and installation drawings developed by ABB. DNV GL was satisfied with the design, installation and tests conducted on the modified system.

Permission to sail with one propulsion unit

Continued passenger voyages on one Azipod

Following first failure

Each Azipod on *Norwegian Star* complied with SOLAS regulations for ship propulsion (manoeuvring and stopping) and steering. Therefore, when the starboard Azipod failed (for the first time), NCLH applied for, and was permitted to sail *Norwegian Star* with just the port Azipod operational, while the starboard exciter unit was being repaired. The decision to sail with one operational Azipod was probably influenced by past reliability of the port Azipod.

Following second failure

The starboard Azipod was tested after the modification and a trialling and monitoring regime established that satisfied the ship's classification society. Regulatory authorities also did not object to proceeding with a single propulsion unit that complied with SOLAS requirements. The decision to proceed was therefore consistent with class and regulatory requirements.

The decisions by NCLH and other parties was on the basis that the alternative excitation system was a proven and used method to excite a motor. Whereas the design concept was proven, the detailed design for the *Norwegian Star* application was not proven in-service. In hindsight, the decision to proceed with normal cruise operations after the second failure, using a single operational pod with a modified exciter installation of unproven operational service was not prudent.

Safe Return to Port regulations

In December 2006, the International Maritime Organisation (IMO) adopted the Safe Return to Port (SRtP) regulations, to place more emphasis on the ability of a ship to safely return to port unsupported after a fire or flooding casualty and for improved survivability in the event of such a casualty. The regulations cover all systems deemed necessary to ensure a safe voyage back to port following a casualty, including propulsion and steering.

The SRtP regulations became mandatory (for new ships) in July 2010 and apply to passenger ships having a length of 120 m or more, or having three or more vertical fire zones. The regulations do not apply to *Norwegian Star* as it was built prior to 2010.

The application of the regulations into the future will potentially improve passenger ship machinery and system redundancy and 'get home' capability. On the matter of whether a post-2010 SRtP compliant ship would be permitted to depart port with compromised propulsive redundancy, DNV GL advised that it is in dialogue with the key passenger ship Flag States and ship owners to establish a common approach. The approach would likely include consideration of the impact of any loss in capability on SRtP compliance, the operational situation (such as the planned route and weather conditions) and countermeasures that may be taken to reduce the operational risk.

Findings

From the evidence available, the following findings are made with respect to the loss of propulsion of the passenger cruise ship *Norwegian Star* that occurred in Bass Strait, about 22 NM south-west of Cape Liptrap on 10 February 2017. These findings should not be read as apportioning blame or liability to any particular organisation or individual.

Safety issues, or system problems, are highlighted in bold to emphasise their importance.

A safety issue is an event or condition that increases safety risk and (a) can reasonably be regarded as having the potential to adversely affect the safety of future operations, and (b) is a characteristic of an organisation or a system, rather than a characteristic of a specific individual, or characteristic of an operating environment at a specific point in time.

Contributing factors

- **The processes for monitoring the condition of the brushless exciter units' electrical insulation were ineffective in detecting deterioration prior to unit failure. [Safety Issue]**
- The brushless exciter unit for the starboard Azipod failed on 11 December 2016. The electrical flashover was probably the result of a deterioration in the electrical insulation between the exciter components.
- The inspection of the port unit, following the flashover failure of the starboard exciter unit, did not include insulation testing of the exciter stator.
- The brushless exciter unit for the port Azipod failed on 24 January 2017. The cause of the failure was similar to that of the starboard unit that failed on 11 December 2016.
- There was an error made in the design of the modified exciter unit used in the repair of the starboard propulsion unit. Clearance between the brush holders and the sliprings was less than required.
- The cause of grooving found on the sliprings of the modified starboard exciter unit was not explored nor remedied prior to the failure of the unit. The slipring grooving was probably a precursor event to the unit's failure.
- The ship operator decided to continue with passenger voyages using a single propulsion unit with a modified exciter unit that had limited operational service.
- The modified exciter unit failed on 10 February 2017 resulting in *Norwegian Star* being adrift in Bass Strait.

Safety issues and actions

The safety issues identified during this investigation are listed in the Findings and Safety issues and 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.

Depending on the level of risk of the safety issue, the extent of corrective action taken by the relevant organisation, or the desirability of directing a broad safety message to the marine industry, the ATSB may issue safety recommendations or safety advisory notices as part of the final report.

Processes for the monitoring of the exciter unit insulation resistance

Number:	MO-2017-003-SI-01
Issue owner:	Norwegian Cruise Line Holdings Ltd (NCLH)/ABB Industry Oy (ABB)
Operation affected:	Marine: Shipboard Operations
Who it affects:	Those responsible for maintaining Azipods

Safety issue description:

The processes for monitoring the condition of the brushless exciter units' electrical insulation were ineffective in detecting deterioration prior to unit failure.

ATSB safety recommendation to NCLH

Action number: MO-2017-003-SR-001

Action status: Released

The Australian Transport Safety Bureau recommends that NCLH reviews the shipboard processes for monitoring the condition of the brushless exciter units used in Azipod installations. The review should incorporate findings from the examination of the failed equipment following the dry docking of *Norwegian Star*.

ATSB safety recommendation to ABB

Action number: MO-2017-003-SR-002

Action status: Released

The Australian Transport Safety Bureau recommends that ABB reviews the manufacturer's instructions for monitoring the condition of the brushless exciter units used in Azipod installations. The review should incorporate findings from the examination of the failed equipment following the dry docking of *Norwegian Star*.

General details

Occurrence details

Date and time:	10 February 2017 – 0134 EDT (UTC + 11 hours)	
Occurrence category:	Incident	
Primary occurrence type:	Loss of propulsion	
Location:	Bass Strait, 22 nautical miles south-west of Cape Liptrap, Victoria, Australia	
	Latitude: 39° 06.8' S	Longitude: 145° 31.8' E

Ship details

Name:	<i>Norwegian Star</i>
IMO number:	9195157
Call sign:	C6FR3
Flag:	Bahamas
Classification Society:	DNV GL
Ship type:	Passenger ship
Builder:	Meyer Werft, Germany
Year built:	2001
Owner(s):	Norwegian Cruise Line Holdings Ltd
Manager:	Norwegian Cruise Line Holdings Ltd
Gross tonnage:	91,740
Deadweight (summer):	10,039 t
Summer draught:	8.60 m
Length overall:	294.13 m
Moulded breadth:	38.10 m
Moulded depth:	11.50 m
Main engine(s):	4 x MAN B&W 14V 48/60 Diesel Engines 2 x ABB VO2300 Azipods, 19.5 MW each
Total power:	58,800 kW electrical output 39,000 kW propulsion power
Speed:	25 knots
Damage:	Damage to sliprings and brush holders in the starboard Azipod exciter unit. Ship disabled and drifting, requiring a tow to return to port.

Sources and submissions

Sources of information

Investigators from the Chief Investigator, Transport Safety (Victoria) under delegation from the Australian Transport Safety Bureau attended *Norwegian Star* on 14 February 2017 while the ship was in Melbourne, Victoria, and again on 22 February 2017 while the ship was in Sydney, New South Wales.

The sources of information during the investigation included:

- Ship owners, Norwegian Cruise Line Holdings Ltd (NCLH)
- Azipod manufacturer, ABB Industry Oy (ABB)
- Classification Society, DNV GL
- Flag State, The Bahamas Maritime Authority (BMA)
- Port State Control, Australian Maritime Safety Authority (AMSA)
- Victorian Ports Corporation Melbourne (VPCM).

References

International Maritime Organisation, 2014, *The International Convention for the Safety of Life at Sea (SOLAS), 1974*, as amended, IMO, London.

International Association of Classification Societies, 2015, *Classification Societies – what, why and how?*, IACS, London.

Det Norske Veritas, 1997, *DNV Rules for Classification of Ships January 1997, Pt.4 Ch.2 Sec.8 Thrusters*, Det Norske Veritas, Norway.

Det Norske Veritas, 2003, *Rules for Classification of Ships Newbuildings January 2003*, Det Norske Veritas, Norway.

Submissions

Under Part 4, Division 2 (Investigation Reports), Section 26 of the *Transport Safety Investigation Act 2003* (the Act), the Australian Transport Safety Bureau (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:

- NCLH
- ABB
- DNV GL
- BMA
- AMSA
- Transport Safety Victoria (TSV)
- VPCM
- Port Phillip Sea Pilots (PPSP)

Submissions were received from NCLH, ABB, DNV GL, BMA, AMSA and TSV. The submissions from those parties were reviewed and where considered appropriate, the text of the draft report was amended accordingly.

Australian Transport Safety Bureau

The Australian Transport Safety Bureau (ATSB) is an independent Commonwealth Government statutory agency. The ATSB is governed by a Commission and is entirely separate from transport regulators, policy makers and service providers. The ATSB's function is to improve safety and public confidence in the aviation, marine and rail modes of transport through excellence in: independent investigation of transport accidents and other safety occurrences; safety data recording, analysis and research; fostering safety awareness, knowledge and action.

The ATSB is responsible for investigating accidents and other transport safety matters involving civil aviation, marine and rail operations in Australia that fall within Commonwealth jurisdiction, as well as participating in overseas investigations involving Australian registered aircraft and ships. A primary concern is the safety of commercial transport, with particular regard to operations involving the travelling public.

The ATSB performs its functions in accordance with the provisions of the *Transport Safety Investigation Act 2003* and Regulations and, where applicable, relevant international agreements.

Purpose of safety investigations

The object of a safety investigation is to identify and reduce safety-related risk. ATSB investigations determine and communicate the factors related to the transport safety matter being investigated.

It is not a function of the ATSB to apportion blame or determine liability. At the same time, an investigation report must include factual material of sufficient weight to support the analysis and findings. At all times the ATSB endeavours to balance the use of material that could imply adverse comment with the need to properly explain what happened, and why, in a fair and unbiased manner.

Developing safety action

Central to the ATSB's investigation of transport safety matters is the early identification of safety issues in the transport environment. The ATSB prefers to encourage the relevant organisation(s) to initiate proactive safety action that addresses safety issues. Nevertheless, the ATSB may use its power to make a formal safety recommendation either during or at the end of an investigation, depending on the level of risk associated with a safety issue and the extent of corrective action undertaken by the relevant organisation.

When safety recommendations are issued, they focus on clearly describing the safety issue of concern, rather than providing instructions or opinions on a preferred method of corrective action. As with equivalent overseas organisations, the ATSB has no power to enforce the implementation of its recommendations. It is a matter for the body to which an ATSB recommendation is directed to assess the costs and benefits of any particular means of addressing a safety issue.

When the ATSB issues a safety recommendation to a person, organisation or agency, they must provide a written response within 90 days. That response must indicate whether they accept the recommendation, any reasons for not accepting part or all of the recommendation, and details of any proposed safety action to give effect to the recommendation.

The ATSB can also issue safety advisory notices suggesting that an organisation or an industry sector consider a safety issue and take action where it believes it appropriate. There is no requirement for a formal response to an advisory notice, although the ATSB will publish any response it receives.

Australian Transport Safety Bureau

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Investigation

ATSB Transport Safety Report Marine Occurrence Investigation

Loss of propulsion on passenger cruise ship *Norwegian Star*
in the Bass Strait, 22 NM SW of Cape Liptrap, Victoria
MO-2017-003
Final – 24 May 2018