United States Coast Guard

Report of Investigation into the Fire Onboard the CARNIVAL SPLENDOR which occurred in the Pacific Ocean off the Coast of Mexico on November 8, 2010, which Resulted in Complete Loss of Power

MISLE Incident Investigation Activity Number: 3897765

U.S. Department of Homeland Security
United States Coast Guard

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United States Coast Guard

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July 15, 2013

FIRE ONBOARD THE CARNIVAL SPLENDOR WHICH OCCURRED IN THE PACIFIC OCEAN OFF THE COAST OF MEXICO ON NOVEMBER 8, 2010, WHICH RESULTED IN COMPLETE LOSS OF POWER

ACTION BY THE COMMANDANT

The record and the report of the Marine Casualty Investigation convened to investigate the subject casualty have been reviewed. The record and the report, including the findings of fact, analysis, conclusions, and recommendations are approved subject to the following comments.

As the Flag State of the CARNIVAL SPLENDOR the Panama Maritime Authority was a Substantially Interested State and had a responsibility for ensuring that a marine safety investigation was conducted into this marine casualty. The U.S. Coast Guard (USCG) was also a Substantially Interested State and, in accordance with international and domestic protocols, had a responsibility to investigate this marine casualty. After consultation, the two agencies agreed that the USCG would lead the investigation in the role of Marine Safety Investigating State. A representative from Panama, members of the National Transportation Safety Board, as well as several USCG Investigators participated in the investigation. Prior to its finalization, this report was reviewed by the Panama Maritime Authority, who agreed with the conclusions and recommendations in the report.

ACTION ON RECOMMENDATIONS

<u>Recommendation 1</u>: Recommend that Carnival Corporation remove the 40-second time delay in the automatic activation sequence for the Hi-Fog system. This should be done in conjunction with Recommendation 2, which addresses immediate casualty control procedures for engine room fires.

The seconds and minutes following the ignition of a fire are crucial to the firefighting response. As such, failure to take quick and prompt action to extinguish a fire can lead to major, negative downstream effects. In this instance, the delay in the automatic activation of the Hi-Fog system, in conjunction with the manual reset of the fire detection system, adversely affected the system performance. If the Hi-Fog system for local protection had been activated without delay, then it is likely that the initial fire caused by the failure of diesel generator 5 would have been contained or extinguished at the deck plate level, thereby preventing spread of the fire to the cable runs and the total loss of power.

<u>Action</u>: I concur with this recommendation. A copy of this report will be provided to Carnival Corporation asking them to consider this recommendation and take appropriate action to implement it fleet wide.

Recommendation 2: Recommend that Carnival Corporation address the conditions listed below in their Safety Management System and/or through improvements to ship systems to eliminate or mitigate risk factors which contributed to this casualty:

a. The corrosion and drainage issues with the air cooler system for all Diesel Generator's (DG).
b. The problems with the slow turn feature of the DGs. In particular, the effect of increasing the slow-turn interval from 30 minutes to 2 hours on the detection of fluid in engine cylinders.
c. The lack of crew familiarity with immediate casualty control procedures for engine room fires.
d. The lack of crew familiarity with the engine room layout and firefighting strategy and procedures for engine room fires.
e. The problems identified with the CO2 system installation and activation procedures, as well as inspection protocols.
f. The susceptibility of the Carnival Splendor and all Dream class vessels to a complete loss of power resulting from damage to a single area of electrical system components in either the forward or aft engine room.

Action: I concur with this recommendation. Of particular concern are items (d) and (f). Although the Carnival Splendor's electrical system is designed and constructed in accordance with applicable international requirements, the International Maritime Organization's (IMO) guiding philosophy in developing new and amended regulations for vessel safe return to port is founded on the premise that future passenger ships should be designed for improved survivability. This is so that in the event of a casualty, persons can safely stay on board as the ship proceeds to port. With this in mind, existing vessels not subject to safe return to port requirements, should be examined to determine the degree of risk associated with their electrical power system design to determine whether these ships are vulnerable to a total loss of power from a localized engine room fire like that experienced by Carnival Splendor.

Fires in high-risk areas, such as the engine room, present many challenges to the shipboard firefighters, such as limited access, fuel and ventilation sources to be secured, various fire-fighting system options, and hazardous machinery. Areas such as the engine room are not frequently traversed by the general crew who comprise fire parties. As such, it is imperative that fire drills be conducted in these spaces to ensure that fire teams are adequately prepared and sufficiently knowledgeable of the ship's arrangement and systems to fight fires in these spaces.

A copy of this report will be provided to Carnival Corporation asking them to consider this recommendation and to take appropriate action to implement it fleet wide.

Recommendation 3: Recommend that at their next annual inspection Lloyd's Register, as the Recognized Organization acting on behalf of Panama, inspect the CO2 systems onboard all Dream class vessels built in the Fincantieri yard for the installation and operational problems uncovered by this investigation.

The CO2 system is a crucial line of defense in extinguishing an engine room fire, and must be installed and maintained properly so that it operates when needed. As the Dream class vessels are based on the Destiny class vessel and were built in the Fincantieri yard, Destiny class vessels should also be considered for review.

Action: I concur with this recommendation. A copy of this report will be provided to the Panama Maritime Authority and Lloyd's Register asking them to consider this recommendation and to take appropriate action to implement it.

Recommendation 4: Recommend that the Commandant, United States Coast Guard, enhance the current guidelines and procedures for the evaluation of fire drills which are conducted as part of Control Verification Exams for foreign vessels.

Fire drills provide an opportunity for Port State Control Officers (PSCOs) to gain a meaningful assessment of the crew's proficiency in firefighting equipment and procedures, as well as ship familiarity. Currently, Navigation and Vessel Inspection Circular (NVIC) 3-08, NVIC 6-03 Change 2 and NVIC 6-91 provide guidance to Coast Guard PSCOs for the conduct and evaluation of fire drills. While this guidance is still valid, it is very high level and based on guidance from the International Maritime Organization to ship owners and operators that carry out fire drills. As such, this guidance should be enhanced to assist PSCOs in better evaluating fire drills, as well as reviewing of records of past fire drills and training.

Action: I concur with this recommendation. A review of existing guidelines and procedures for the evaluation of fire drills noted in the recommendation will be performed to identify where appropriate enhancements can be made to improve the ability of Port State Control Officers to assess a crew's proficiency in firefighting equipment, procedures and vessel familiarity with firefighting strategies and procedures. The results of that review will then be used to amend the appropriate guidance. In the meantime, an immediate message will be sent to Port State Control Officers to advise them of the pertinent findings of this investigation and to give them awareness of the key issues identified as the result of this investigation.

Recommendation 5: As the United States representative to the International Maritime Organization (IMO), recommend that the Commandant, United States Coast Guard, advocate for and make a recommendation to the IMO for improved guidance for fire drills onboard all ships subject to the requirements of the International Convention for the Safety of Life at Sea.

Although this casualty illustrates that improved guidance on the conduct and evaluation of fire drills is something that may be necessary, it would be difficult to put this into effective practice through Coast Guard action alone without a parallel effort at the IMO to improve guidance internationally.

Action: I concur with this recommendation. The Coast Guard will submit a proposal to the Maritime Safety Committee at IMO for inclusion of this item to the work program of the appropriate subcommittees.

In addition to the above recommendations, a copy of this report shall also be provided to Cruise Lines International Association to be shared among its worldwide members.

[redacted]

J. C. BURTON
Captain, U.S. Coast Guard
Director of Inspections & Compliance

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24 JUN 2013

MEMORANDUM

From: [redacted]
Lead Investigating Officer [redacted]
To: Commandant (CG-INV)

Subj: INVESTIGATION INTO THE FIRE ONBOARD THE CRUISE SHIP CARNIVAL SPLENDOR ON NOVEMBER 8, 2010

EXECUTIVE SUMMARY

On November 8, 2010 at 0600 (Local Time), the Carnival Splendor was underway off the coast of Mexico when the vessel suffered a major mechanical failure in the number five diesel generator. As a result, engine components, lube oil and fuel were ejected through the engine casing and caused a fire at the deck plate level between generators five and six in the aft engine room which eventually ignited the cable runs overhead. The fire in the cable runs was relatively small, but produced a significant volume of smoke which hampered efforts to locate and extinguish it. In addition, the fire caused extensive damage to the cables in the aft engine room, which contributed to the loss of power.

It took fire teams approximately two hours to locate the fire in the cable runs. Once located, the fire teams attempted to extinguish it with CO2 and dry powder portable extinguishers. However, the fire was not fully controlled by these agents due to a lack of cooling of the cable conductors which held heat and caused the cable insulation and jacket materials to continue to burn. Approximately five hours into the firefighting effort, the Captain evacuated the engine room and attempted to activate the installed CO2 system. The first attempt to activate the CO2 system from the remote location failed. Subsequently, ship's crew attempted to activate the system manually from the CO2 room. The second attempt also failed because the section valve for the aft engine room was inoperable. Additionally, after pressurizing the CO2 system numerous fittings and hose connections within the CO2 system leaked. In the end, no CO2 was released into the aft engine room.

At 1315, the fire in the cable runs was extinguished, which was most likely due to a lack of oxygen resulting from closure of the watertight doors during the attempt to use the fixed CO2 system. Afterwards, vessel engineers were unable to restart the unaffected main generators due to extensive damage to cables in the aft engine room. Throughout the response, the emergency generator and back-up battery system provided power for emergency services.

There were no injuries or fatalities as a result of this marine casualty, and the vessel safely reached the port of San Diego on November 11, 2010.

Post casualty analysis of the event revealed that the installed Hi-Fog system for local protection was activated 15 minutes after the initial fire started. This delay was the result of a bridge watchstander resetting the fire alarm panel on the bridge. This was a critical error which allowed the fire to spread to the overhead cables and eventually caused the loss of power. While the fire was eventually self-extinguished, the failure of the installed CO2 system and the poor execution of the firefighting plan contributed to the ineffectiveness of the crew's firefighting effort.

As a result of this casualty and the initial findings by investigators, the Coast Guard issued two safety alerts which covered the operation, testing and maintenance of CO2 systems. Furthermore, Carnival took steps to evaluate fire safety systems, firefighting doctrine & training, procedures for inspection & testing of installed safety systems. Specifically, Carnival has removed the 40-second time delay from the automatic activation sequence for the Hi-Fog system and has implemented short and long-term solutions to rectify the problems associated with the activation of the CO2 system.

There are five safety recommendations in this report which are addressed to Carnival, Lloyd's Register, Panama and the Coast Guard. The recommendations address the conditions onboard the Carnival Splendor which contributed to this casualty, as well as, the problems with the CO2 system installation on all Dream class vessels. In addition, the recommendations to the Coast Guard address the need for improved guidance to enhance the conduct and evaluation of fire drills.

A. FINDINGS

1. General

Photograph 1 - CARNIVAL SPLENDOR
Photo taken from http://carnival-news.com/

The Carnival Splendor is a steel, passenger cruise ship constructed for Carnival Corporation by Fincantieri - Cantieri Navali Italiani S.P.A. at its yard in Genoa Italy. The vessel was constructed under Registro Italiano Navale Rules and at delivery transferred to Lloyd's Register (LR). The Carnival Splendor is a Dream class vessel and was delivered on July 30, 2008. It has a maximum speed of 22 knots and is driven by a diesel electric propulsion plant. The plant consists of six identical Wartsila 46, twelve cylinder, four stroke cycle diesel engines arranged in two engine rooms that power two propulsion motors.

2. Vessel Particulars

Owner..Carnival Corporation
Flag ....Panama
Hull Number 6135
Call Sign..3EUS
Classification Society.........................Lloyd's Register
Lloyd's Register Number..................9333163
IMO Number.....................................IMO 9333163
Gross Registered Tonnage 113,300
Net Registered Tonnage.....................85,850
Deadweight Tonnage 99.5
Number of Decks 17
Total Lifesaving Capacity..................4,914
Maximum Guests 3,734
Maximum Crew 1,180

Length Overall ....290.2 meters
Length P-P (Perpendiculars).............247.7 meters
Beam at Waterline.............................35.5 meters
Beam at Bridge Wings.......................41.6 meters

3. Machinery Data

Diesel Engines	6 x 12 cylinder, Wartsila 46C 1050 kW/cylinder Total Installed Power: 75.6 MW
Generators..	6 x 14,000 Kva 3 Phase AC; 60 Hz; 11,000 volt
Emergency Generators.......................	1500 kW Isotta Fraschini-Marelli
Propulsion Motors..............................	2 X 21 MW 146 rpm; 2830 volts, reversible
Automation System............................	Valmarine, APSS Damatic XD
Switchboard	M.V. Imesa L.V. Schneider
Fire/Smoke Detection System...........	Autronica – Norway
CO2 Extinguishing System...............	Wormald
Water Mist/Sprinkler System............	Marioff Hi-Fog® Fire Protection System Marioff-Finland

4. Vessel Examinations and Status

As a foreign flagged vessel operating in U.S. waters and embarking U.S. passengers, the Carnival Splendor is subject to examination by the U.S. Coast Guard as detailed in Coast Guard Navigation and Inspection Circular 03-08, to ensure the vessel meets the requirements of the International Safety of Life at Sea Convention (SOLAS) and Title 46, U. S. Code Section 3505. Prior to the incident on November 8, 2010, the Carnival Splendor possessed a current Certificate of Compliance issued on November 15, 2008. In addition, the U.S. Coast Guard conducted an annual Control Verification Exam on November 7, 2010.

With respect to compliance with the requirements in the International Management Code for the Safe Operations of Ships and for Pollution Prevention (ISM Code), Carnival Cruise Lines (Carnival) was issued a Document of Compliance on August 23, 2008 and the Carnival Splendor was issued a Safety Management Certificate on December 17, 2008.

When the Carnival Splendor departed port on November 7, 2010, there were no outstanding deficiencies with the material condition of the vessel, and the vessel was in compliance with the ISM Code requirements.

5. Timeline of Events
(ALL Times are Pacific Standard Time using a 24-hour clock unless otherwise noted)

Planned Itinerary for Cruise Commencing November 7, 2010

Sunday	November 7, 2010	Long Beach, California
Monday	November 8, 2010	At Sea
Tuesday	November 9, 2010	At Sea
Wednesday	November 10, 2010	Puerto Vallarta, Mexico
Thursday	November 11, 2010	Mazatlan, Mexico
Friday	November 12, 2010	Cabo San Lucas, Mexico
Saturday	November 13, 2010	At Sea
Sunday	November 14, 2010	Long Beach, California

November 7, 2010 - Passenger Changeover and Pre-departure Activity

At 0712, the Carnival Splendor tied up to its berth in the port of Los Angeles / Long Beach, California. The vessel had returned from a recent trip to the Mexican Rivera and was preparing for another seven day trip by disembarking passengers, taking on consumables, food supplies and fuel, and embarking new passengers.

In addition to embarking passengers, U.S. Coast Guard inspectors boarded the Carnival Splendor to perform a Port State Control Cruise Ship Examination. This exam focused primarily on various safety equipment and procedures, and included observation of fire fighting and emergency drills, and rescue boat and lifeboat evolutions as well as a thorough check of all the vessel's statutory certificates and documentation.

At 1700, a passenger muster drill and safety briefing was conducted. At 1735, the ship was unmoored and transited out of the harbor, letting go of the Harbor Pilot at 1803. The vessel began its first leg of the seven day cruise with all systems operating as normal. The vessel departed port with 3,299 passengers and a crew of 1167.

November 8, 2010 – At Sea

On the morning of November 8, 2010, the Carnival Splendor was underway in the Pacific Ocean approximately 150 nautical miles South of San Diego in approximate position 30-09.76 N, 116-45.65 W. The vessel was on a heading of 158.6 degrees making approximately 20 knots, en route to Puerto Vallarta, Mexico.

At 0551, the Second Engineer, Third Engineer and an Engine Cadet were on watch in the engine room. The Second Engineer was in the Engine Control Room (ECR). The Third Engineer and Engine Cadet were on roaming watch in the engine room. Diesel Generators 2, 3, 5 and 6 were online and equally loaded providing power to the propulsion motors and for ship service power. The engine room ventilation dampers and watertight doors for the aft engine room were open in accordance with company policy.

Event – Catastrophic Failure of Diesel Generator 5

At 0558, Diesel Generator 5 (DG 5) experienced a torsional vibration alarm.

At 0559, DG 5 experienced a fail start alarm. In response to the alarms, the Second Engineer on watch sent the Third Engineer and the Engine Cadet to investigate. As they made their way to the lower engine room on Deck C, the Third Engineer and Cadet reported hearing an explosion followed by the rapid development of black smoke. The Third Engineer and Cadet retreated to the ECR which began to fill with smoke. The second engineer simultaneously trained his CCTV camera in the area above DG 5 and momentarily noted flames before his camera view was obscured by smoke. Shortly after the ECR filled with smoke, the engineers on watch evacuated the ECR.

At 0600, Second Engineer shut down DG 5 and 6 and notified the Chief Engineer of the situation in the engine room. The engineers on watch initiated emergency procedures for an engine room fire, which included shut down of the machinery space ventilation system, and closure of the engine room dampers, fire screen doors, watertight doors and quick-closing fuel valves. The Hi-Fog system was not manually activated by the engine room watchstanders.

Event – Fire in Aft Engine Room

At 0600, the automatic fire detection system in the aft engine room was activated and numerous visual and audible alarms were activated on the bridge Emergency Management System (EMS) panel. In addition, the engineers on watch phoned the bridge to notify them of the situation in the engine room.

At 0601, the deck officer announced, "There is a fire, is a fire" to the personnel on the bridge and then initiated the crew response. Then, via the Public Address system, the deck officer ordered the Alpha Team to proceed to the diesel generator aft.

At 0601, two fire/smoke detectors above DG5 and DG6 were activated. Within seconds of activation of these detectors, a bridge watch officer performed a general reset of the fire detection system. As a result of this action, all fire/smoke detectors returned to a normal status.

By 0603, the fire and smoke detectors above DG5 and DG6 were in a fault status. As a result, the Hi-Fog system for local protection was not automatically triggered by the fire detection system.

At 0604, the Captain arrived on the bridge and took command of the firefighting efforts.

Event – Activation of the Hi-Fog system

At 0604, the Hi-Fog system for local protection is activated in the Fuel Oil Purifier room (Deck C, Fire Zone 4).

[This was the first area where the Hi-Fog system was activated. The Hi-Fog system was subsequently activated in other machinery spaces as recorded in the EMS log. However, activation of the Hi-Fog system in the vicinity of the DG5 and DG6 did not occur until 0615.]

At 0606, the Quick Response Team (QRT) arrived in the staging area followed shortly afterward by Fire Teams Alpha, Bravo and Charlie. The staging area for all fire teams was at the Deck 0 engine room entrance.

At 0609, the QRT entered the engine room to assess the situation.

[The following timeline entries have been abbreviated and only denote the significant events or actions in the firefighting effort. From 0609 to 1054, all of the Fire Teams were rotated in succession to assess the situation and extinguish the fire. The coordination of Fire Teams is best captured in the Captain's Firefighting Timeline as well as the Voyage Data Recorder transcript.]

Event - Loss of Primary Power

At 0610, DG3 and DG6 tripped offline and the vessel lost all sources of primary electrical power. Shortly thereafter, the Emergency Diesel Generator (EDG) automatically started.

Event - Loss of Emergency Power

At 0611, the EDG stopped running. As a result, the ship's battery system kept critical safety systems online, such as the emergency lighting system.

At 0611, the Hi-Fog system pumps experienced a fault condition. As a result, Hi-Fog system pressure was maintained by the back-up nitrogen cylinders.

At 0614, the Cruise Director informed the passengers of the situation via the Public Address system.

At 0615, the Hi-fog system for local protection was automatically activated in the vicinity of DG5 and DG6. As a result, the machinery section valves for the aft engine room were opened and water mist was supplied by the Hi-fog nozzles above DG5 and DG6.

At 0625, the Cruise Director ordered all crewmembers to their general emergency stations, and ordered all passengers to the open decks.

At 0631, the general emergency alarm was activated.

At 0636, power from the EDG was restored. As a result, the Hi-Fog system pumps came back online.

At 0806, Fire Team Charlie entered the engine room accompanied by the Staff Chief Engineer and the Second Engineer.

At 0821, Fire Team Charlie located the fire above DG 5. The team observed that electrical cables were burning, and observed no oil or additional combustible materials.

At 0830, the Captain ordered the fire teams to use portable dry powder and CO2 extinguishers on the fire.

At 0851, QRT and Staff Chief Engineer extinguished the fire above D/G 5 with the portable dry powder and CO2 extinguishers.

At 0905, Captain ordered staff to activate ventilation and to open doors to aft engine room to remove smoke from the space.

At 0947, Staff Captain reported that the fire above DG 5 re-flashed and that the aft engine room was filled with smoke. QRT extinguished fire with portable extinguishers.

At 1015, Fire Team Charlie reported the fire above DG 5 re-flashed. Fire Team Charlie extinguished with portable extinguishers.

At 1021, the Captain ordered staff to close all shell doors and engine hatch cover.

At 1054, the Chief Engineer reported that there was a fire on DG 5.

At 1054, the Captain decided to activate the CO2 system in the aft engine room. Prior to releasing the CO2, the Captain requested the Chief Engineer verify that the engine room dampers were closed and the space was evacuated.

At 1103, watertight doors 7 (forward door to the aft engine room) and 8 (aft door to the aft engine room) are closed.

At 1104, the hard switch dampers and ventilation closure stops for Fire Zone 2 (the aft engine room) are activated. Activation was unsuccessful due to several elements being in fault condition. All fire teams are evacuated from the engine room and ordered to staging area.

Event – Remote Activation of CO2 System Failed

At 1113, the Captain ordered the Chief Engineer to release CO2 into the aft engine room. The Chief Engineer attempted to release the CO2 by using the remote station on deck zero located outside the ECR. The CO2 activation was unsuccessful.

Event – Loss of Emergency Power

At 1126, the EDG stopped running.

Event – Activation of CO2 System Failed

At 1146, the Captain ordered activation of the CO2 system from the back-up local controls in the CO2 room on the 11th deck port side. The Staff Captain and Staff Chief Engineer used the master panel to activate the valve to Section A for the aft engine room. The pilot manifold filled up and provided an indication alarm, but the start and discharge sequence failed. Upon entry into the CO2 room, the crew observed the valve on the pilot cylinder leaking and the valve for Section A remained closed. The crew also observed numerous gas leaks from the flexible connectors between the CO2 cylinders and the manifold. The crew switched the system to the other pilot valve and attempted to activate the system manually by opening the manifold valves at the heads. Upon opening of the manifold valves, the crew observed gas leaking from multiple fittings in CO2 system. Closer inspection revealed that the arm of the gas activated piston that admits CO2 to the aft engine room (Section A) fell off. The officers attempted to use a wrench on the valve stem and were unable to open it. The gauge on the system above the valve indicated 50 bars of pressure. No CO_2 was released except incidentally into the CO_2 room due to leaks at fittings, hoses, and connections.

At 1215, power from the EDG restored.

Event - Fire above DG5 and DG6 Extinguished

At 1315, the Staff Chief Engineer entered the engine room. He observed smoke in the engine room, but no fire. He reported the temperature in the engine room was 165°F.

At 1358, the Staff Captain reported that there was no fire on DG 5 and that the engine room temperature was decreasing.

At 1431, the crew installed a fan to supply cold air to the engine room, which in turn dropped the temperature in the aft engine room to 74°F.

At 1511, the crew extinguished a small fire in the cabling above DG 4. Fire patrols were set up to monitor the aft engine room throughout the night.

Action – Vessel Towed to Port

Following the fire, ship's crew was unable to restart the diesel generators. As a result, the vessel had no power for the propulsion motors and the vessel was towed to the port of San Diego, California. During the transit, the EDG provided power for emergency services.

No passengers or crew were injured as a result of the engine failure and subsequent fire.

6. Engine Room Details

a. Engine Room Layout

The Carnival Splendor has two engine rooms: the forward engine room and aft engine room. Diesel Generators (DGs) 1, 2 and 3 are located in the forward engine room. DGs 4, 5 and 6 are located in the aft engine room. The engine rooms are separated by a watertight bulkhead. The figure below shows the arrangement of the aft engine room. The Engine Control Room (enclosed in blue rectangle), the location of the fire (red solid rectangle), location of the watertight bulkhead between the forward and aft engine rooms (red vertical line) and general area of the damaged cable runs (yellow oval) are noted in Figure 1.

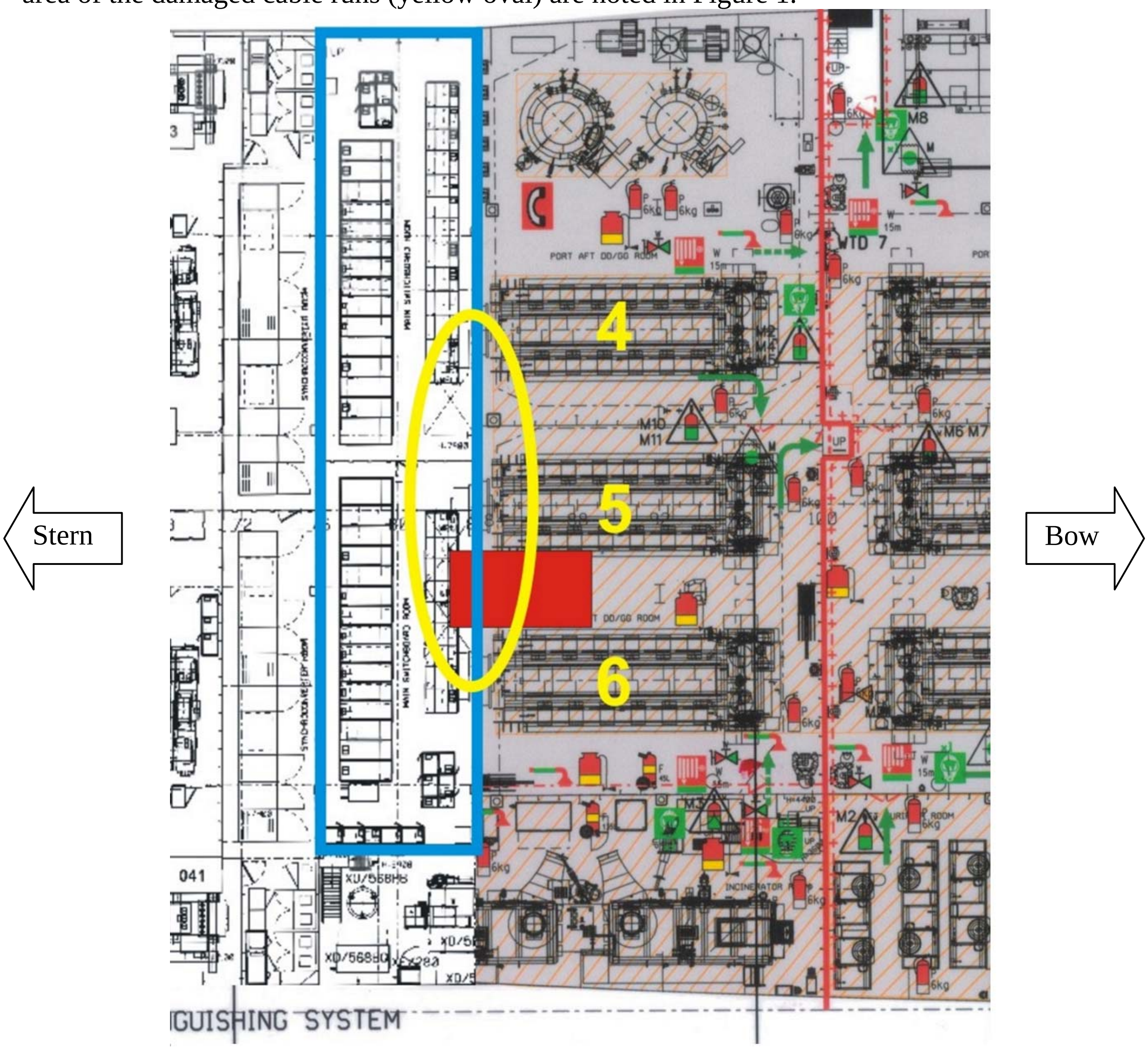


Figure 1 - Excerpt from Fire Control Plan showing aft engine room; annotated by Coast Guard.

b. Engine Control Room

The Engine Control Room (ECR) is the key operating area for all vessel remotely controlled and monitored engineering activities. The ECR is located on the zero deck with access to the aft and forward machinery spaces, it houses the main control console. The main control console includes the automation systems as well as a variety of mimic consoles, graphical display equipment, computers, the Wartsila Engine Control System (WECS) and other control systems. Within the ECR are various automation cabinets, emergency diesel generator starter panels, electrical management mimic boards, a Hi-Fog system management console, valve controllers, automation batteries, APIS system and engineering workstations, printers, desks, references and other equipment.

c. Damatic DNA

Each engine WECS is connected to the ship automation system, Damatic DNA. All the functions of the alarm system, power management system, and ballast, bilge, and other miscellaneous systems are integrated into the Damatic DNA system. The system provides the man machine interface and communication via keyboards, tracker balls and graphic video display units. More than 150 video mimic displays are available in logical and clear diagrams. For each sensor, parameters, time delays, set points and tuning of controller loops can be adjusted. Connected to this system are alarm printers and other storage devices capable of capturing and storing operational data and alarm conditions as measured throughout the machinery spaces and in other parts of the vessel.

The Damatic DNA system provides an advanced graphical display of engine parameters. The system can also perform calculations and display mean exhaust gas temperature for each engine initiating an alarm if a cylinder exhaust gas temperature is achieved or if the deviation from the mean value exceeds a preset limit. It also has the capability of storing operational data indefinitely on other integrated data management systems. The Carnival Splendor uses a system known as APIS.

d. Engineering Watches

Normal engineering watches onboard the Carnival Splendor consist of a second engineer and third engineer and a motorman working four hours on with eight hours off, unless they have other responsibilities. The motorman generally works and makes rounds in the engineering spaces. The second engineer is stationed in the engine control room (ECR) and the third engineer may be there or in the engineering spaces.

Total primary engineering staff (not including day working maintenance and repair personnel):

1 – Chief Engineer	1 – First Engineer
1 – Staff Chief Engineer	4 – Second Engineers
1 – Senior First Engineer	6 – Third Engineers

7. Fire Protection Systems and Equipment

a. Fire Zones

The Carnival Splendor is divided into seven fire zones numbered one through seven, aft to forward and separated by the dark vertical lines in the figure below. The aft engine room is located in fire zone two.

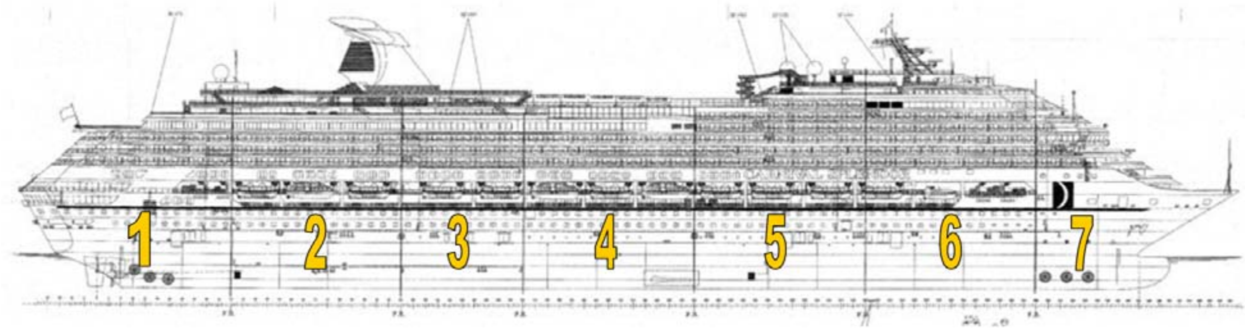


Figure 2 - Profile view of vessel showing location of Fire Zones

b. Fire Detections System

The vessel is equipped with an Autronica fire detection system. It consists of all the equipment used to monitor and detect heat, smoke and flame throughout the vessel. Smoke, heat and flame detectors located in critical areas of the vessel including the machinery spaces are linked to the closed circuit television (CCTV) system and under certain conditions the detectors should trigger the cameras to provide real-time video feeds of the affected areas.

c. Emergency Management System

This Autronica system is connected to the vessel's Emergency Management System (EMS), which is MARTEC supplied Safety Monitoring and Control System. The EMS is a computer-based data system that serves as an interface to the safety subsystems. It detects all alarms created by the subsystems and presents to the EMS operators a graphic man/machine interface using vector-based mimics. It provides operational and control functions of the various systems it interfaces with. The system is connected to the fire detection system, ESD, the Hi-Fog system, watertight door system and the ship's voyage data recorder. The man/machine interface is designed to show the operator all the events coming from the sub systems in a suitable and ergonomic way. The EMS and its display are located in the vessel's command room/safety center with additional work stations on the bridge and engine control room.

d. Emergency Shutdown System

The vessel is equipped with a MARTEC Emergency Shutdown System (ESD). It enhances the operation of the various firefighting systems and controls ship ventilation, dampers system, smoke extraction, vessel fire doors, watertight doors and machinery automation to limit the spread of fire, smoke and intake of air that could increase the process of combustion. It interfaces with the vessel's CO_2 system, fire detection system, watertight door system and vessel automation with respect to machinery emergency stops.

e. Full Flood CO_2 Fire Extinguishing System

The vessel is equipped with full flood CO_2 fire extinguishing system (CO_2 system) which services the engine room as well as other machinery spaces. The CO_2 system components, piping and other elements were supplied by Wormald (part of the Tyco group of companies), Dalmine (which provided the bottles and low pressure distribution piping) and installed by Fincantieri (F/C). Actual installation was performed by subcontractors of F/C. The main CO_2 system bottles and release system are located on the 11th deck port side. There are 89 CO_2 cylinders and two pilot bottles with related release cabinets for nine different zones. The system also includes seven cylinders for other galley areas throughout the vessel. The system has pneumatic configurations driven by two pilot cylinders. The pilot cylinders are activated by a solenoid valve on top of the cylinder and controlled by levers inside each release cabinet. Substations consisting of mimic release stations are located on the zero deck near the engineering offices, bunker station, and entrance to the engine control room. The subsystem also uses two nitrogen bottles to activate the main system on the 11th deck.

Each cabinet is keyed and sounds an alarm when opened. Within each cabinet are two valves that are turned in a specific sequence. When turned, besides allowing gas flow to certain devices, they also activate micro switches that perform other functions such as securing ventilation systems, and engines within an effected space, and closing watertight doors. Onboard the Splendor, the system is designed to use the pilot bottles to activate and open the group of main bottles for the space in which the gas is being released first. Moving the second valve handle opens the main stop valve to the space in which the gas is being released.

f. Marioff Hi-Fog® Fire Protection System

The vessel is equipped with a Marioff Hi-Fog® fire protection system which was designed for accommodation and machinery spaces. Machinery spaces are protected by the Hi-Fog® local protection system (Hi-Fog system). The specially designed spray nozzles (Hi-Fog nozzles) cause water to enter the space as a fine fog (mist) at a very high velocity. The small droplets yield a very large total water surface area, providing efficient cooling of the fire and surrounding gases. The high speed of the small droplets should enable the fog to penetrate hot flue gases and reach the combustion source. Accommodation spaces, public areas, store rooms, etc., are covered by the automatic sprinkler system.

The Marioff Hi-Fog® fire protection system consists of two skid package mounted type pumps and nitrogen actuator systems and various panels and programmable logic controls throughout the vessel. The system has the capability to continue to supply suppression fluid even when power is lost. Within the machinery spaces, the Hi-Fog system can be manually activated from the operating panel in the engine control room or automatically activated by the Autronica fire detection system. For automatic activation to occur within a machinery space, two fire/smoke detectors must be in alarm status for at least 40 seconds in order for the machinery space zone valve to open.

8. Firefighting Procedures and Training

a. Safety Management System

Carnival's Safety Management System (SMS) is a comprehensive, electronic, web-based system consisting of the manual, job descriptions, procedures, circular letters that provide additional procedural guidance, compliance verification information, environmental operational controls, occupational health and safety, a security manual and other information. It includes safety notices, the Shipboard Oil Pollution Emergency Plan (SOPEP), Carnival Corporation information, telephone directories, environmental management system appendices, checklists, forms, and a procedure matrix. The contents of the SMS are contained in nearly 5,000 electronic files, which occupy over half a gigabyte of electronic storage space. The Republic of Panama issued the Carnival Splendor its Safety Management Certificate based on a verification performed by Lloyd's Register of North America (LRNA) which stated that the vessel complies with the requirements of the International Management Code for the Safe Operation of Ships and Pollution Prevention (ISM Code). The verification was completed, officially stamped and signed on December 17, 2008.

The SMS contains procedures for responding to emergencies, which are contained in "SMS Procedure P002 Fire Onboard". The following is an excerpt from this procedure:

> 4.*1 General*
>
> *The aim of this procedure is to establish a guideline for the Masters, Chief Engineers, Hotel Directors and, in general, for all ship's Officers to follow in case a fire onboard is reported. The attached check list is to be used both by the OOW and the EOW according to the scenario.*
>
> *4.2 Topics*
>
> *Investigation: Any time a fire alarm sounds on the relevant mimic panel the first action to be ordered by the OOW is the investigation by the Fire Patrol on duty (which may include the Security Guard on duty as applicable). All alarms must always be investigated. If the investigation ends in a false alarm or a fault in the system, the printout from the mimic panel will be kept for monitoring purposes and in order to carry out further repairs or maintenance actions. If the alarm is real all actions described by the Ship's Muster List and by this procedure must be implemented.*
>
> *Action to be taken: All shipboard personnel must be familiar with the firefighting theories and with the main firefighting appliances that are installed and/or provided onboard. The shipboard personnel that discover the principle of the fire must immediately inform the Bridge with any possible means of communications (telephone, manual fire alarm, etc.). He/she must then remain in the area until the arrival of the investigation team, conditions of the area permitting. Furthermore, according to the dimension of the fire, the crewmember shall be able to secure the area closing the fire screen doors. Different actions shall be taken according to the location of the fire (see dedicated checklists):*

Fire engulfing the Engine Room
Fire engulfing the passengers and crew accommodations including external areas and kitchens

4.3 Check lists/Forms

Following check list and forms must be used for the implementation of this procedure whenever required.
EMERGENCY/P002/CL1
EMERGENCY/P002/CL2

b. Firefighting Standard Operating Procedures (SOP)

In addition to the procedures in the SMS, Carnival and the Marine Technical Institute – Maritime Professional Training, Ft. Lauderdale, Florida, developed a policy document entitled "Standard Operating Procedures for Shipboard Firefighting". This document was not part of the vessel's electronic Safety Management System (SMS), hard copy firefighting manuals, or other related documentation onboard. The document provides guidance on marine firefighting, and contains the most information on "Alpha Code" emergency drill procedures, roles, and responsibilities.

The following excerpts are from the document and applicable to this casualty.

Section: General Guidelines Fighting Fire aboard Carnival Vessels

Confine the fire - Identify means of controlling the fire.
1. *Close the access to the affected area.*
2. *Close the fire screen doors adjacent to the affected area.*
3. *Shut down ventilation to the affected area.*
4. *Are the automatic fire systems activated?*

Extinguish the fire - A fast aggressive attack of any fire is preferred. After sounding the alarm, if safely possible, attack a small fire with the nearest fire extinguisher.
1. *Identify and need to rescue victims from the affected are.*
2. *Identify the class of Fire.*
3. *Identify the class of extinguishing agent to be used.*
4. *Gather information about the atmosphere inside the affected area.*
5. *Choose an offensive or defensive attack on the fire.*
6. *Communicate all of this information appropriately.*

1.2 Systems Monitoring: This position will be a stationary position on the Bridge. This person will monitor all systems on the ship using the existing equipment.

1.7 Planning: The person(s) assigned this task will be responsible for assisting the Master in the planning process, with the aid of the appropriate fire plan, for future operations such as:

1.7.1 Boundary Cooling Needs,
1.7.2 Ventilation Needs,
1.7.3 De-Watering Needs,
1.7.4 Medical Evacuation Needs, and
1.7.5 Ship Evacuation Needs.

2. Engine Control Room Responsibilities

2.2 Ventilation - The person(s) assigned this task will be responsible for the following:

2.2.1 Shut down ventilation in affected area,
2.2.2 Communicate with bridge to formulate and implement the ventilation plan,
2.2.3 Insure not to spread the heat smoke and fire gasses to an occupied space,
2.2.4 Insure not to spread fire to areas not affected.

2.3 Electricity - The person(s) assigned this task will be responsible for the following:
2.3.1 Shut down electricity to the affected area, and
2.3.2 Activate emergency lighting.

2.6 Hi-Fog - The person(s) assigned this task will be responsible for the following:
2.6.1 Maintain pressure
2.6.2 Maintain water supply. After discharging fresh water start salt water.

3. Staging Area Responsibilities

3.1.3 Brief Fire Squads on assigned tasks:
1. *Fire Squad briefed as to the task they will perform*
2. *Mode of attack that will be used — Offensive or Defensive*
3. *Type of search pattern selected — Left Hand or Right Hand*

3.1.7 Control ventilation of fire area as condition present.
Positive Pressure Ventilation planning
1. *Identify avenue for smoke and gases to travel*
2. *Consider use of natural ventilation*
3. *Consider need to reposition the vessel to use natural ventilation*
4. *Consider use of fixed ventilation systems*
5. *Identify locations for fans to assist in air movement*
6. *Identify locations for protective Iine placement*
7. *Ensure personnel are in place and ready*
8. *Ensure that attack teams and ventilation teams are ready.*
9. *Monitor effectiveness of ventilation effort*
10. *Shut down effort lf not effective.*

5.2 Engineering Spaces

5.2.2.2 Initial Response

1. *Evacuate spaces in and around affected area and carry out roll call.*
2. *Seal all watertight doors and fire doors.*
3. *Shut down ventilation and power into spaces.*
4. *Set security around area for crowd control and movement of non-essential personnel.*
5. *Initiate low level lighting in the spaces around and above the scene.*
6. *Have MSDS information for that space on hand.*
7. *If sprinklers are activated, is there water on the deck and/or in the bilge or is all of it being converted to steam by the heat?*
8. *Identify if the paint is burning off of the deck plates and bulkheads, signs of high heat close to the deck may indicate a possibility of a flashover event.*
9. *Initial attack should be followed quickly by a foam attack, especially if fire is in bilge area- DO NOT USE FOAM IF STILL FLOWING HIGH VELOCITY WATER FOG OR WATER STREAM.*
10. *Initial attack should be made by Engine Room Squad and the QRT team and it should be broken into 2 man teams as follows:*
    - *2 men on hoseline (s)*
    - *2 men dedicated to SAR w/ TIC (if victims are present).*
    - *2 men dedicated backup and hoseline handlers per hoseline.*
11. *Immediately stage boundary cooling around the affected space.*
12. *Sweep all accommodation areas around the space for any unreported victims.*
13. *Set up for ventilation out of stack or other vertical runs such as stairwells, stage fans and hoselines to protect and prevent extension of smoke into unaffected areas.*
14. *Ventilate once fire crews are on scene flowing water, this will aid in SAR and extinguishment of fire.*

- *DO NOT VENTILATE UNTIL FIRE CREWS ARE IN PLACE AND READY.*
- *DO NOT VENTILATE IF CO2 OR HALON HAS BEEN RELEASED INTO THE SPACE.*

c. Alpha Code

An “Alpha Code” emergency call is the highest level of emergency firefighting call onboard the vessel. When an “Alpha Code” is announced along with the location of the fire, it calls into action the vessel’s human firefighting components. There was no information about the “Alpha

Code" in the Safety Management System documentation, firefighting manual or safety officer's manual. However, the "Alpha Code" was mentioned in the "Standard Operating Procedures for Firefighting", and the roles of vessel personnel for an "Alpha Code" call were posted on the vessel's muster list.

According to the "Standard Operating Procedures for Firefighting", when the Alpha Code emergency call is broadcast, senior personnel with emergency duties should report to their stations and, on the bridge, the captain should assign someone or several persons to handle various responsibilities: documentation, systems monitoring (EMS system), communication, hazardous materials research, security, medical, and planning throughout the event, and notes that the captain may adjust the team at will.

Another team is set up in the ECR during Alpha Code emergency calls. Here the chief engineer oversees communication, controlling ventilation, controlling electricity, water supply, dewatering, the Hi-Fog System, CO2, system monitoring, and hazardous materials research.

As the support systems are set up, the QRT and firefighting teams set up in an announced staging area, safe from the area of the fire. The QRT originates from the fire patrol. The four fire teams or fire squads are lettered alphabetically and formed by crewmembers. Fire teams A and B consisted of deck/steward personnel, and fire teams C and D consisted of engine department personnel.

At the time of the incident on November 8, 2010, the document "Standard Operating Procedures for Firefighting" was not incorporated as official policy within the vessel's Safety Management System and there was no other information describing Alpha call emergency drills. However, Carnival indicated that the Captain of the vessel was familiar with the policy and viewed it as guidance.

d. Firefighting Training

Carnival's safety and fire training falls into four categories:

1. Onboard training, drills, and exercises
2. Basic, Mandatory safety training for deck and engine personnel under the International Maritime Organization's (IMO's) Standards of Training, Certification, and Watchkeeping (STCW).
3. Advanced firefighting for deck and engine personnel.
4. Voluntary Basic Safety Training for hotel personnel (which is the same as 2 above).

Carnival maintains a schedule of the above training which is carried out at regular intervals to ensure each crewmember has the requisite training based on their duties and requirements.

B. CAUSAL ANALYSIS

1. Catastrophic Failure of Diesel Generator 5

a. Post-Casualty Inspection of Diesel Generator 5

Post-casualty inspection of the DG 5 prime mover revealed a catastrophic failure primarily involving the components of one set of cylinders. The failures of the two connecting rod and piston assemblies in the A1 and B1 locations on DG 5 destroyed the engine so that it was no longer usable. The connecting rod upper components sheared from the connecting rod lower parts on two cylinder sets. Connecting rod upper part B1 was in two pieces in the oil sump, while connecting rod A1 (780 lbs) had ejected out of the crankcase.

Both pistons were broken and were liberated from the crankcase. Both piston crowns were cut from each piston skirt. The B1 piston gudgeon pin was found in the sump, while A1 was ejected from the crankcase. The heaviest component ejected was the crankshaft counterweight which landed on the starboard side of the engine between DG 5 and DG 6 in the primary burn area. The free end side of the counterweight of crank number one had been ejected from the crank case damaging the engine block on its way. The lower halves of each connecting rod were seized on the crank pins (crank shaft journals). The lower parts of the cylinder liners were each destroyed and the engine block severely damaged.

Photograph 1 - Connecting rod, upper part A1 (780 lbs) ejected from DG5 and found on deck plates in aft engine room.

Photograph 2 - - Connecting rod, upper part B1 in two pieces found in the oil sump

Photograph 3 - Lower halves of A1 and BA connecting rods for DG5, each were seized on the crank pins (crankshaft journals).

Photograph 4 - Crankshaft counterweight from DG5, A1/B1 cylinder. Counterweight was ejected from engine and landed between DG5 and DG6 in the primary burn area.

b. Failure Analysis of the B1 Connecting Rod by Lucius Pitkin, Inc.

Photograph 5 - B1 Connecting Rod for DG5
Post-casualty photo provided by Wartsila

Carnival hired consulting engineers Lucius Pitkin, Inc. (LPI) to evaluate a number of failed components from DG 5. Of particular interest was the B1 connecting rod. Regarding the B1 connecting rod that failed in two pieces and had a visible bend, the LPI reports states:

> *"Results of the evaluation conducted indicated that the subject connecting rod failed by progressive fracture in the nature of high cycle, low stress fatigue. The origin of the connecting rod fracture could not be determined due to the severe impact damage to the fracture surface. Nevertheless, the crack origin of a secondary fatigue crack evident approximately 5.5 in. above the primary fracture surface was determined to be at the*

extrados of the bent connecting rod shank. This indicated that the fatigue crack most likely initiated as a result of increased surface stresses at the extrados after the connecting rod shank was bent. It further indicated that it is likely that the fracture origin of the primary fracture was also located in an area of raised surface stress at or near the connecting rod extrados."

Note: An extrados is an exterior curve of an arch.

The LPI engineers provided an estimate on the amount of time it would take for these high-cycle, low-stress type of fatigue failures to occur, and gave an estimate of three to 324 operating hours, based on a constant speed of 514 RPM. Carnival representatives stated LPI's methodology and analysis was very conservative and that the timeframe for the initial bend to have occurred extended further back in time.

LPI reported that the stress state in the connecting rod was "not present from the beginning of the diesel engine's service life" and that the "bend in the connecting rod shank elevated surface stress in the shank to a sufficient level to initiate fatigue cracking which propagated and caused the connecting rod to fracture."

c. Diesel Generator 5 Operating Data and Maintenance Records

DG5 was started at 2136 on November 7, 2010 and had been running for approximately 8 hours and 24 minutes before it failed on November 8, 2010. In order to gain a better understanding of the operating hours and parameters, engine operating records were requested from Carnival. Of the six main diesel generators onboard the Carnival Splendor, only the main bearing temperatures of one engine was recorded and maintained for historical purposes. No additional historical data was kept pertaining to engine operating pressures or temperatures, of exhausts, lube oil, fuel oil, air charge, coolants, etc.

While the vessel had the technology and software systems to collect the information, the systems were not set up to capture and store the data. Furthermore, engineers did not have a system in place to manually record engine data, and were not required to review engine operating parameters. Further investigation revealed that this was common practice on many Carnival vessels.

Carnival employees stated that when repairs were needed, before and after "screen prints" of operating parameters were printed out to note changes in parameters. Given the work on the DG5 on November 4, 2010 and air cooler problems experienced in the summer of 2010, "screen prints" and/or records of this work was requested from Carnival. This information was not provided.

While there was no historical data maintained by the engineers, alarm data was recorded by the WECS monitoring system interface with the DAMATIC system. The DAMATIC system contained 2,246 pages of line by line alarm records which covered a period from May 24 to November 8, 2010 for various systems throughout the engineering plant as well as all vessel systems. This data was held in internal memory. Printed alarm data was also available, however some periods of time were unavailable. During analysis, it was noted that some important engine alarms that were recorded in the printed alarm data were not captured in the DAMATIC system. It is unknown if all the systems were capturing all the alarms that the systems receive.

Additional data, such as diesel generator start and stop times were available in a system called the NAPA Engine log, which documents some operational events but not operational parameters. Electrical load data which includes engine running hours, kilowatt load, ship operating data, and performance and efficiency measurements was provided out of an element of the NAPA system which delivered the information to Carnival shore offices in Miami, Florida. Data from the NAPA Engine Log was only available back to June 2010.

d. Examination of Diesel Generator 5 Alarm Data

As indicated in the timeline of events, the engineers on watch noted a torsional vibration alarm just prior to the catastrophic failure of DG 5 on November 8, 2010. A torsional vibration alarm is indicative of an imbalance in an operating engine and may be caused by a variety of conditions. Representatives for Wartsila conveyed that when considering the causes of torsional vibration alarms occurring with an engine, one must consider what is normal operation for the particular engine being examined. Furthermore, they indicated that an excessive imbalance in firing pressures or misfiring in a cylinder; a damaged flexible coupling between the engine and the alternator, or mechanical damage in the crankshaft/connecting rod rotating components lending to an imbalance of masses may lead to a torsional vibration alarm.

Historical evidence of torsional vibration alarms for DG 5 was preserved in the APIS system which captures engine information data. A review of the APIS logs revealed the following torsional vibration alarms for DG5:

- Prior to July 21 2010, there was one occasion where the torsional vibration alarm of DG 5 activated. The alarm was attributed to an electrical overload circumstance where other generators were having difficulties with maintaining load.

- On July 21, 2010, something occurred with DG 5 when the high temperature cooling water system inlet pressure dropped and caused a low/low level (pressure) alarm, accompanied by a torsional vibration alarm and a shutdown initiation. A momentary complete plant blackout followed.

- On August 13, 2010, within a minute of starting, DG 5 went into a torsional vibration alarm status.

- On October 21, 2010, during starting DG 5 experienced a torsional vibration alarm and nearly simultaneous oil mist shutdown alarm. The following day the head gasket and head was replaced for cylinder B4 of the engine.

- On November 5, 2010 during starting, DG 5 experienced a torsional vibration alarm. The head gasket was replaced later that afternoon.

e. Head Gasket Replacement on Diesel Generator 5 on November 5, 2010

According to the Senior First Engineer, DG 5 was secured on November 4, 2010 in order to replace the fuel pump and fuel injector for the B1 cylinder. Following completion of this work, no test run was conducted. At 1111 on November 5, 2010, DG5 was restarted by the Third Engineer on watch. The Chief Engineer was also in the ECR when DG5 was restarted. DG5 operated for 4 minutes and 53 seconds before it experienced a torsional vibration alarm. The engineers on watch diagnosed the problem as a blown head gasket on the B1 cylinder which was likely the result of fuel oil in the cylinder.

Photograph 6 (below) was taken by Carnival employees during the head gasket replacement. The cylinder surfaces show significant carbonization which indicates incomplete combustion. While this phenomenon may have been attributed to a bent connecting rod, the engineers involved in the work did not make that diagnosis, and did not observe any problems with the engine which led them to believe there were issues with the B1 connecting rod.

Photograph 6 - DG5, B1 cylinder liner, piston crown and gasket
Photo taken by Carnival employees during head gasket replacement on November 5, 2010

Following the head gasket replacement, DG5 was operated for the following intervals:

- November 5, 2010 from 1815 to 1827
- November 6, 2010 from 0844 to 1444
- November 6, 2010 from 1520 to 1735
- November 7, 2010 from 0251 to 0256
- November 7, 2010 from 2136 to time of engine failure on November 8, 2010 at 0558.

With the exception of the alarms on November 5, 2010 and November 8, 2010 (just prior to the failure of DG5), no torsional vibration alarms were noted during the above operation intervals.

f. Documented Air Cooler-Receiver Problems

An air cooler is a component on a diesel engine that removes the heat of compression added to the air as it passes through the compressor side of an engine's turbocharger. It is a heat exchanger. The air is provided for combustion in the cylinders of the diesel engine. On the Wartsila engine the air cooler is actually composed of two heat exchangers that utilize low temperature and high temperature coolant water flow. Depending on the amount of cooling that takes place and the humidity in the air, moisture will form in the air cooler and should be drained away. The air is then led as "charge air" to a receiver, where it enters the connections to the 12 cylinder heads. The engine instruction manual provides guidance on the importance of minimizing the amount of condensate formed by adjusting the coolant flow through the heat exchanger.

Carnival Dream class vessels coming out of the Fincantieri yards were noted as having air cooler drainage problems as far back as October 2009, and Fincantieri, Carnival and Wartsila were aware of the air cooler problems. At that time, Wartsila recommended the following to manage the problem:

- Utilize individual drainage piping lines from each engine to a storage tank instead of using manifold systems where several engines are connected to the same drainage line (the common "as built" practice on Dream class vessels);
- the use of an air-gap to a funnel to provide visual confirmation that drainage was taking place; and that
- drainage piping be connected to an increasingly sized diameter pipe.

Besides the Carnival Splendor, other Carnival vessels had instances where hydrolock was a concern due to poor heat exchanger drainage. According to November and December 2009 email communications provided by Wartsila, Carnival Dream's DG5 had excessive accumulations of water within the receiver and charger air cooler of the engine noted only after an incident with an engine. An engineer secured the engine after very high exhaust gas temperature was observed and further inspection revealed water dripping from various flanges and connections of the receiver system. The drainage piping was opened and several hundred liters of water were removed. DG2 of the same vessel also showed similar conditions. The Senior First Engineer of the Carnival Dream also reported that an identical problem occurred onboard the Carnival Freedom.

Onboard the Carnival Splendor as recently as July 12, 2010, the B bank of DG5 was discovered to have a severely corroded, destroyed and leaking air cooler heat exchanger. The cause of the corrosion was suspected to be: 1) failed drainage of the condensate formed on the outside of the tubes and away from the heat exchanger, 2) a leaking heat exchanger tube, and 3) backflow from other operating engines when the engine is secured or during temporary exposure from other leakages such as when the exhaust gas boiler flooded back to the engine during refilling. Photograph 7 shows the bottom of the heat exchanger having rusted away almost a complete steel 27 plate between its frames. Photograph 8 shows the plate of a new heat exchanger having slightly different construction.

Photograph 7 - Corroded heat exchanger from DG5. Photo provided by Wartsila, taken on July 12, 2010

Photograph 8 - New heat exchanger for comparison. Photo provided by Wartsila

After the July 2010 incident, check valves were installed in the piping for DG 4, DG 5 and DG 6. During the investigation, a number of Carnival employees stated that fluids and moisture from operating engines would back flow into the air coolers of engines that were secured due to the design of the piping system and absence of check valves. The back flow was due to the fact that they shared a common line leading to the tank and lacked check valves.

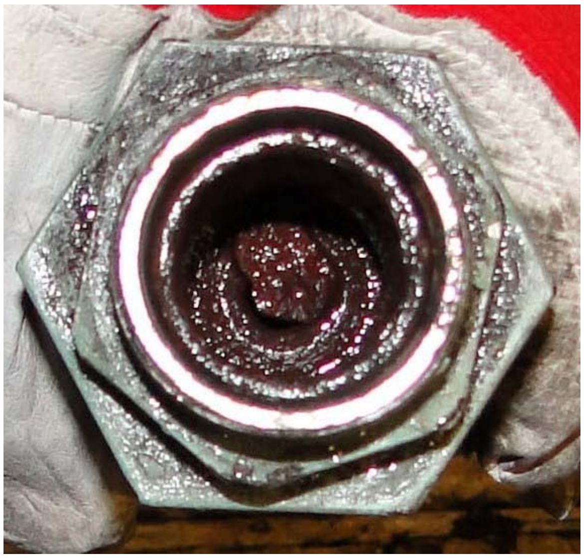
Regarding operation of the air cooler, Chapter 3 of the Wartsila manual states, "*The charge air temperature should be in principle as low as possible at loads higher than 60%, however, not so low that condensate occurs…*"

The Wartsila training manual indicates that one of the important measured running parameters for monitoring engine performance is the pressure differential over the charge air coolers. The engines onboard the Splendor were not fitted with pressure gauges locally that measured the pressure drop across the heat exchangers. The vessel did have a hand-held device provided by Wartsila that could be used to monitor and check the differential pressure as needed or when there was a suspected of a problem. It is unknown if the engineers regularly used the tool. Previous drainage systems on the air cooler included a ball valve to atmosphere to check for flow and a sight glass that if properly cleaned could be used to verify flow from system.

Post-casualty inspection of the DG5 air coolers revealed significant quantities of ferrous oxide scaling and rust in the air cooler base area and outlet areas of the B side of DG 5 air cooler, as shown in Photograph 9 and Photograph 10. The heat exchangers were tested and found not to be leaking. The receiver runs the length of the engine and connects to the air inlets of both banks of heads. In Photograph 11, scale is shown in a drain valve connection on the pressure side of the orifice when the engine is running. There is no evidence of screens or other devices to protect against the clogging of the drains by rust particles within the air cooler. Photograph 12 provided by Carnival shows the sight glass of the B1 cooler. The sight glass developed a visible haze over the inspection port which obstructed the viewing port and made observation of water flow very difficult.

Photograph 9 - DG5 air cooler, outlet area

Photograph 10 - DG5 air cooler, outlet area



Photograph 11 - DG5 air cooler, drain valve connection.

Photograph 12 - DG5 air cooler, sight glass for B1 cooler.

Post-casualty, the A side of the DG5 air cooler was also found in a stage of deterioration. Its casing area was also heavily contaminated with ferrous oxide/rust. Its base also showed significant evidence of deterioration.

Photograph 13 - DG5, A side air cooler.
Photo taken by Wartsila

Photograph 14 - DG5, A side air cooler.
Photo taken by Wartsila

Considering the heat exchangers were replaced in July 2010, the deterioration of the DG 5 air coolers was alarming. As such, other factors may have contributed to the deterioration of the heat exchangers such as a lack of coatings, the use of dissimilar metals, and insufficient electrical grounding.

g. Hydrolock

One phenomenon which may result in a torsional vibration alarm as well as prevent a piston from reaching its designated height in the cylinder is hydraulic locking or "hydrolock". It occurs when a critical amount of incompressible liquid enters an engine's combustion space before the compression stroke. The incompressible liquid then obstructs the upward piston stroke, increasing combustion chamber pressure to potentially damaging levels. Damage can occur to a variety of the mechanical components such as the cylinder's connecting rod, piston, piston pin, head and head gaskets, valve assemblies and other components. If such damage were to occur, it may result in a torsional vibration alarm.

In order to prevent hydrolock, the Wartsila 46C is equipped with a "slow turn" system. This feature provides one primary function prior to starting of the engine: If enough liquids accumulate in a cylinder to obstruct engine rotation during slow turning, the turning should stall and cause a "slow turn mechanical failure" alarm. The alarm notifies the operating engineers that there is a failure that they need to immediately investigate and the engine is prevented from starting automatically. The presence of the slow turn system allows the engines to be marketed for auto-start applications. The slow turn system is controlled by the Wartsila Engine Control System (WECS) and most elements of its functionality cannot be modified by the vessel's crew.

In addition to the slow turn system on the Wartsila 46C engine, the Wartsila manual onboard the vessel states the following: *"Due to the automatic slow turning function it is not required to turn the engine with air before starting, but always when there is time available turn the crankshaft* *two revolutions with turning gear keeping the stop lever in the stop position and the indicator valves open...”*

The standard slow turn interval recommended by Wartsila is 30 minutes. Before the building of the Carnival Splendor, Costa Cruise Lines, a Carnival sister company, asked Wartsila (through Fincantieri) during the construction of a Costa vessel if Wartsila had an objection to increasing the slow turn interval in order to “save air” and reduce the amount of room needed for the air bottles. Wartsila expressed no objection, but stated that increasing the interval would increase the risk of not detecting a hydraulic lock at the original frequency. To Wartsila's recollection, neither Fincantieri nor Carnival asked Wartsila to express an opinion concerning the slow turn interval for the Dream class vessels, which are very similar to the Costa vessels.

Post-casualty, Carnival consulted Wartsila in the spring of 2011 regarding the slow turn interval. Wartsila recommended setting the interval to the standard 30 minutes. It should be noted that such a change would require significant engineering modifications which may or may not be reasonably possible without major technical considerations and alterations onboard the vessels.

According to Wartsila and Carnival, the slow turn feature does not generate sufficient force to damage an engine during the slow turn. As mentioned previously, an engine will stall during slow turn if fluid is in an engine cylinder. However, while the slow turn feature can prevent an engine from being started and damaged, a closer look at the logic behind the slow turn feature revealed that there are circumstances when an engine can be started without going through a slow turn. Specifically, an engine can be started without going through a slow turn if the engine has been run or slow turned within 120 minutes of starting it. In addition, if an engine is started from the start solenoid at the local engine controls, the engine will start without going thru a slow turn. Thus, in the absence of a slow turn during start-up, the fluid in an engine cylinder may go undetected and may result in damage to the engine.

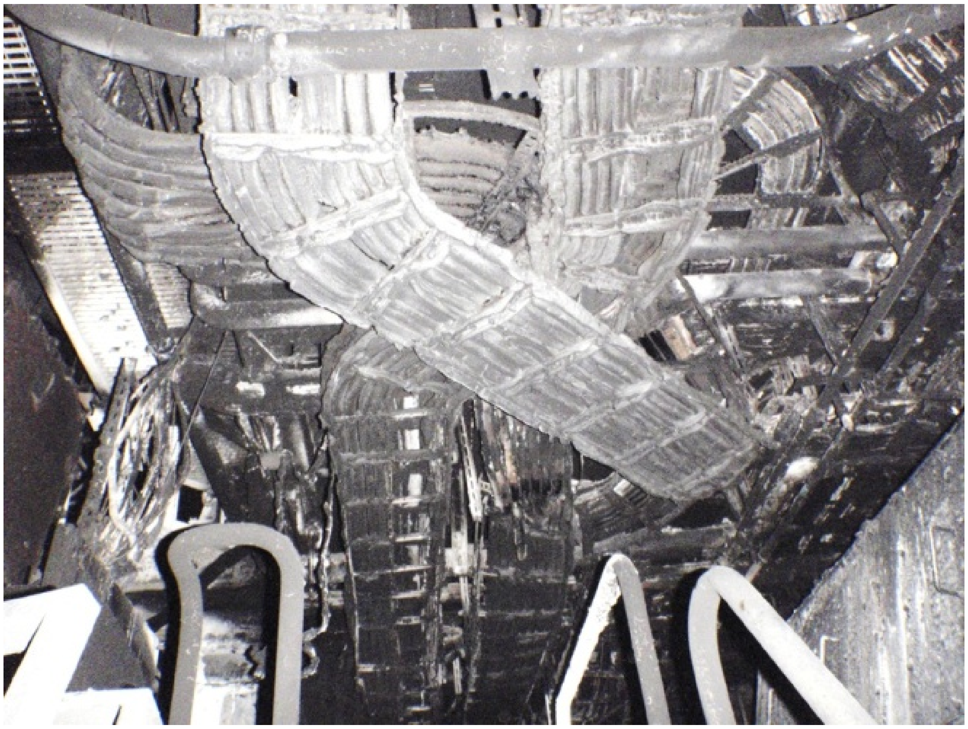
As noted previously, a review of all available alarm data showed no slow turn mechanical failures associated with DG5 except during July of 2008. However, on September 6 and 7, 2010, the slow turn mechanical failure alarm of DG1 alarmed six times over a period of 12 hours beginning at 21:34:39 on September 6 and ending at 09:12:00 on September 7 each time the generator attempted to do a slow turn. At 1017 in the morning on September 7, the engine’s turning gear was engaged and ultimately a head gasket was replaced. While the incident with DG1 was not directly related to the failure of DG5, the failure of the ship’s crew to identify the cause of the slow turn mechanical alarm for DG1 indicates the crew lacked procedures and/or training for responding to such an alarm.

2. Fire

The following photographs document the fire damage in the aft engine room.

Photograph 15 – Rear section of DG5

Photograph 16 - DG5 valve covers, B1 and B2 cylinders



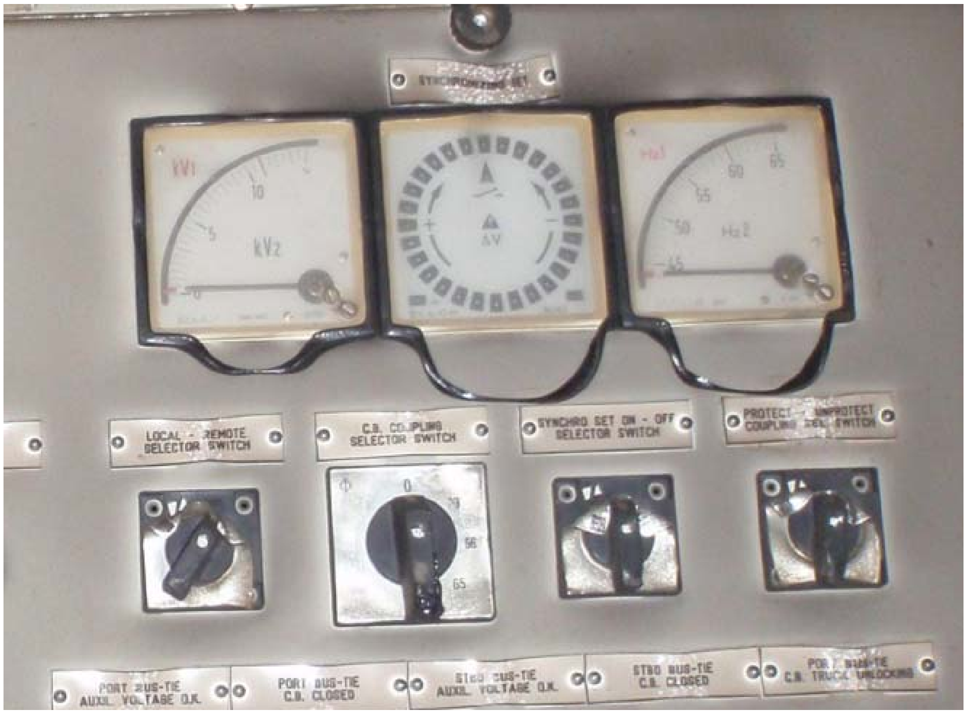
Photograph 17 – Overhead cable runs between DG5 and DG6

Photograph 18 – Overhead cable runs above DG5 and DG6

Note the location of the Hi-Fog nozzle below the cables runs

Photograph 19 – Vertical cable runs; note bare cables due to fire damage

Photograph 20 – Cables above DG4 showing melted orange cable covering



Photograph 21 – Console in starboard switchboard room showing melted plastic components.

a. Fire Analysis by Burgoyne Incorporated

Carnival hired consulting scientists, engineers and fire investigators from Burgoyne Incorporated to investigate the fire and share their findings. According to Burgoyne, Inc., the fire originated at the platform level between DG 5 and DG 6. It started as a pool fire on the floor plates between the engines but also consisted of burning lube oil spray from the damaged pre-lube pump assembly. The fire was ignited by the burning fuel oil coming out of the engine both off the last ignition events occurring in the cylinders and possibly lit off from hot components ejected from the cylinders.

The consulting scientist's draft report stated that based upon a two square meter fire on the platform, the melting of aluminum valve covers about nine feet above, on both engines five (B side of the engine) and engine six (A side) the heat release rate was estimated to be about two and a half megawatts, and determined to consume about 106 gallons of lube oil per hour. It was noted that a significant and unquantifiable amount of lube oil entered the bilges but did not ignite and thus the total amount of oil involved with the fire was not determined.

For a general point of reference, a one megawatt fire would be similar in size to that of a large fabric living room chair fully engulfed in flames.

b. Hi-Fog System Performance

The machinery spaces on the Carnival Splendor are equipped with a Hi-Fog local protection system. The Hi-Fog system is the first line of defense in suppressing an engine room fire. However, in this instance, it was ineffective at extinguishing the initial fire between DG5 and DG6.

As noted previously, the initial fire started at 0600 when engine components were ejected from DG5 and ignited a pool fire between DG 5 and 6. In the vicinity of the initial fire at the deck plate level between DG5 and DG 5, there are 4 detectors (2 smoke, 1 flame and 1 combined) above DG 5 and 4 detectors (2 combined, 1 smoke and 1 flame) above DG 6.

Note: The following information was obtained from the EMS log:

At 06:00:20 (hh:mm:ss), the first fire/smoke detector above DG5 was activated. Subsequently, another fire/smoke detector was activated 13 seconds later. Once 2 fire/smoke detectors are activated, the Hi-Fog system was programmed with a 40 second time delay before the zone valve(s) for the aft engine room are opened.

At 06:01:07, a bridge watch officer reset the alarm panel on the bridge. As a result, the alarm system went into detection mode and all fire/smoke detectors returned to a normal status.

At 06:01:07, a total of 3 fire/smoke detectors above DG6 are activated.

At 06:01:23, a bridge watch officer reset the alarm panel on the bridge. As a result, the alarm system went into detection mode and all fire/smoke detectors returned to a normal status.

By 06:02:56, the four detectors above DG 5 are in fault status due to their destruction by fire.

By 06:03:03, the four detectors above DG 6 are in fault status due to their destruction by fire.

When detectors are in fault status, they are not considered active and will not trigger the Hi-Fog system.

At 06:04:12, the Hi-Fog system for local protection is activated in the Fuel Oil Purifier Room. Subsequently, the Hi-Fog system is activated in other machinery spaces.

At 06:15:52, the Hi-Fog system is activated for the aft engine room. The section valves supplying the Hi-Fog nozzles above the DG5 and DG6 are opened.

The following information was pulled from the EMS log. It shows the sequence for activation of the Hi-Fog system for local protection in machinery spaces.

<u>System time (Local time) – Section Valve No. – Location (Deck & Fire Zone)</u>

1) 13:40:35 (6:04:12).............HF-M1.......... Fo Do Purifiers (Dk C Fz 4)
2) 13:41:12 (6:04:49).............HF-M14........ Garbage Room (Dk 0 Fz 2)
3) 13:42:58 (6:06:35).............HF-M7.......... FWD DD/GG Middle (Dk C Fz 3)
4) 13:44:33 (6:08:10).............HF-M8.......... FWD DD/GG Port (Dk C Fz 3)
5) 13:44:38 (6:08:15).............HF-M6.......... FWD DD/GG Stbd (Dk C Fz 3)
6) 13:52:15 (6:15:52).............HF-M16........ ECR (Dk 0 Fz 2)
7) 13:52:15 (6:15:52).............HF-M17........ Waste Silo A (Dk A Fz 2)
8) 13:52:15 (6:15:52).............HF-M18........ Waste Silo B (Dk A Fz 2)
9) 13:52:15 (6:15:52).............HF-M4.......... FWD Boiler (Dk C Fz 2)
10) 13:52:15 (6:15:52)...........HF-M3.......... Incinerator Room (Dk C Fz 2)
11) 13:52:15 (6:15:52)...........HF-M9.......... Incinerator Room (Dk A Fz 2)
12) 13:52:15 (6:15:52)...........HF-M5.......... AFT Boiler (Dk C Fz 2)
13) 13:52:15 (6:15:52)...........HF-M2.......... Lo Purifier (Dk C Fz 3)
14) 13:52:15 (6:15:52)...........HF-M15........ Emergency DD/GG (Dk 11 Fz 2)
15) 13:52:15 (6:15:52)...........HF-M10....... AFT DD/GG Stbd (Dk C Fz 2)
16) 13:52:15 (6:15:522).........HF-M12....... AFT DD/GG Port (Dk C Fz 2
17) 13:52:15 (6:15:52)...........HF-M13........ Garbage store (Dk 0 Fz 2)
18) 13:52:15 (6:15:52)...........HF-M11....... AFT DD/GG Middle (Dk C Fz 2)
19) 13:52:24 (6:16:01)...........HF-M1.......... Fo Do Purifiers (Dk C Fz 4)
20) 13:52:24 (6:16:01)...........HF-M6.......... FWD DD/GG Stbd (Dk C Fz 3)
21) 13:52:24 (6:16:01)...........HF-M7.......... FWD DD/GG Middle (Dk C Fz 3)
22) 13:52:24 6:16:01) ....HF-M8.......... FWD DD/GG Port (Dk C Fz 3)
23) 13:52:24 (6:16:01)...........HF-M2.......... Lo Purifier (Dk C Fz 3)
24) 13:53:14 (6:16:51)...........HF-M7.......... FWD DD/GG Middle (Dk C Fz 3)
25) 13:53:14 (6:16:51)...........HF-M8.......... FWD DD/GG Port (Dk C Fz 3)
26) 13:53:16 (6:16:53)...........HF-M6.......... FWD DD/GG Stbd (Dk C Fz 3)
27) 13:53:29 (6:17:06)...........HF-M1.......... Fo Do Purifiers (Dk C Fz 4)

Figure 1 shows the location of the fire as well as the sequential activation of the fire/smoke sensors. Within 2 minutes, the smoke traveled beyond fire zones 2 and 3. As a result, the Hi-Fog local protection system was activated in machinery spaces outside of the affected area.

The Hi-Fog system can be manually activated from the ECR. Based on the EMS logs, it does not appear that the engineering watch manually activated the Hi-Fog system for the engine room before evacuating.

As a result of the intervention by the bridge watch officer, the activation of the Hi-Fog local protection system for DG 5 and 6 was delayed by approximately 15 minutes. By the time the Hi-Fog system was activated, the fire had spread to the cable runs over DG 5 and 6. Since the Hi-Fog system was designed for local protection, the nozzles were positioned below the cables runs and the Hi-Fog system was not effective in suppressing or extinguishing the fire in the cable runs.

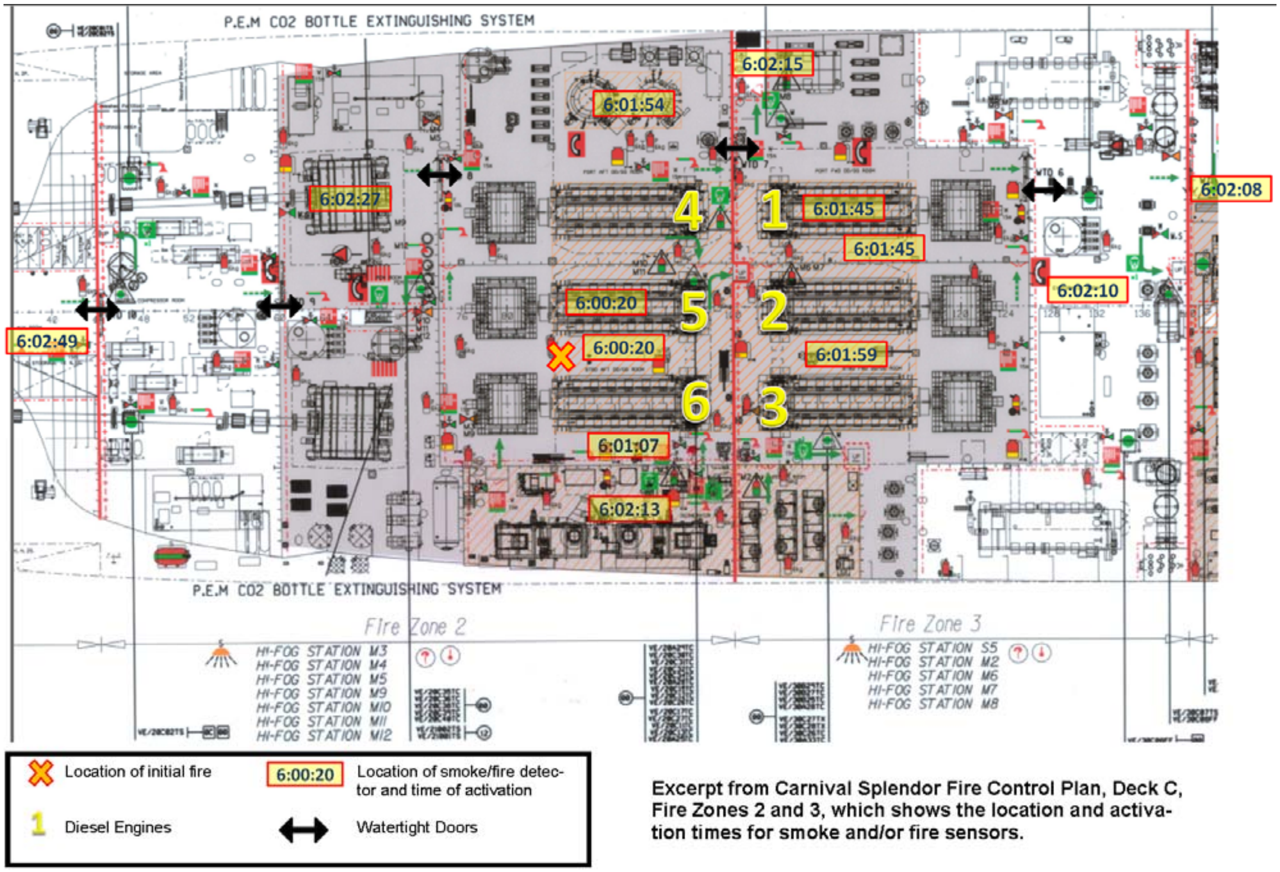


Figure 1 - Excerpt from the Carnival Splendor Fire Control Plan showing Deck C, Fire Zones 2 and 3 Plan annotated by USCG

c. Failure of the Installed CO2 System

1) Post-casualty inspection of the CO2 system

When investigators arrived onboard several days after the casualty, the CO_2 system remained pressurized and the ball valves associated with the aft machinery space and the vent to atmosphere were unable to be turned and opened with the cheater bar that fits into the arm of the valve stem. The purpose of the bar is for manual operations so that the valves can be opened in a complete no power emergency.

The system was eventually bled down using the relief valve circuitry. Once the pressure was taken off the system, the main three inch ball valve to the aft machinery space was able to be turned freely with the cheater bar provided, as was the identical sized ball valve that vents the system to atmosphere.

When the piping segment associated with the discharge leading to the aft machinery space was taken apart a small amount of moisture drained out and some corrosion was noted (see

Photograph 22). In addition, hemp type packing was noted at various pipe fittings and seal screwed connections (see Photograph 23).

Photograph 22 - CO2 system, 3-inch ball valve to aft machinery spaces

Photograph 23 - Photo showing hemp packing in CO2 system fittings

Many connections using hemp leaked. In one control cabinet, the control valve handles had been incorrectly fitted. A number of the fasteners securing the actuating arms to different control valves were discovered loose.

2) Analysis of the CO2 System by Lucius Pitkin, Inc.

Upon agreement of the interested parties, component parts of the CO2 systems were shipped to Lucius Pitkin, Inc. for metallurgical and other testing. Their analysis revealed the following:

- The intended method of operation produces a differential pressure across the section valves that likely prevented the main valves from opening.
- The actuating levers were inadequately attached to the valve stems, causing the actuating lever to detach when an attempt was made to manually operate the system.
- Water present in the system corroded the pipes and body of section valve A.
- Numerous CO2 leaks were found in the system when an attempt was made to operate the system.
- Due to incorrect installations, pieces of hemp used to seal screwed connections had been carried through the system and became lodged in the non-return valves preventing them from seating.

- The levers on the ball valves in one control cabinet had been incorrectly fitted, such that the valves were open when the lever positions showed the valves to be closed.

3) International Rules Change/Order of Operation for Ball Valves

Regarding the operation of the three-inch ball valves leading to the protected spaces: The International Maritime Organization has been aware of certain difficulties with the operation of high-pressure CO2 systems and the use of ball valves in circuits leading to protected spaces. On May 18, 2006, in resolution MSC.206(81), the Maritime Safety Committee (MSC) made amendments to the Code for Fire Safety Systems that now requires high pressure CO_2 system releasing controls to be interlocked so that the control which conveys gas to the protected space is operated first, and the control that causes the discharge of the gas from its storage containers is operated second, and that the controls can only be operated in that order. This specific change came about as a result of ball valves failing to open when subjected to a high pressure differential across them.

4) Hemp Sealant / Advisory Notice

Hemp is an old fashioned fibrous and low-grade, twine-type, pipe thread sealant. During an inspection of the CO_2 system onboard the Crown Princess (now Pacific Jewel) on March 15, 2009, as part of the Passenger Safety Certificate Renewal survey performed by Wilhelmsen Ships Service, a CO_2 system servicing vendor, discharge problems with the system were uncovered. The cause was found to be debris, which included hemp fibers in the pilot line non-return valves. It was reported that a similar situation had existed as early as 2007 but was assumed to be a shipyard defect.

Princess Cruise Lines took corrective action and notified Carnival Corporation, specifically Maritime Policy and Compliance (MP&C) regarding this issue. It was recalled that similar occurrences had been noted in the past related to new builds and compromised non-return valves. MP&C issued an advisory notice on April 14, 2009 to the 12 brands and eight management entities that make up Carnival Corporation to raise awareness of the issues. The advisory notice indicated that there was a potential risk for accidental release of CO_2 into the wrong space if the pilot valve non-return valves leaked into un-intended spaces and suggested that the operating lines take necessary steps to ensure that similar problems do not exist on other ships.

5) Documented Problems with the CO2 system

Prior to the vessel's delivery, the system was inspected and approved by the shipyard representatives at F/C, a Carnival shipbuilding safety inspector, RINA (the classification society during construction), and an independent certified inspector from an agency recognized by RINA.

On May 7, 2009, the following issues were discovered by Wilhelmsen Ships Service technicians during the first annual service and inspection of the vessel's CO2 system:

- All the remote release stations on Deck 0 were non-functional because the non-return valves located on Deck 11 in the pilot lines were installed backward.

- The pneumatic actuating system for the directional valves for the aft engine room and the forward engine room were installed backwards (which would release CO2 in the wrong space).
- Mismatch of the actuating components between the main switchboard and fuel separator room.
- Despite the various cross connections, indicating lights indicated the proper locations were being activated.
- The main discharge line leading to the battery room was obstructed with a 30-cm zinc plug.

As a result of these issues, Carnival took aggressive action to correct the deficiencies and ensure all sister vessels based on the original Carnival Destiny design were checked by their operators. Additionally, Carnival reviewed inspection reports and conducted additional inspections for the remaining Carnival vessels built in the other yards of the F/C group.

6) CO2 System Activation Procedures

The firefighting manual available to officers onboard the Carnival Splendor referred to a CO2 system but not the one that was installed onboard the vessel. Related system photographs, images, schematics and diagrams were also found to be inaccurate.

A review of CO2 system documents revealed a RINA approved test memoranda dated October 20, 2006, which established the following procedure for testing the CO2 system: 1) select the zone or line, 2) observe the shutdowns of ventilation systems, machinery and other warning alarms and then 3) move to the gas-release procedure, which included cylinder selection for the particular zone and verification of pressurization of the manifold, etc. Another document that appears to be part of a RINA approval letter dated December 28, 2008, describes the operational procedure in exact reverse order.

In this instance, ship's crew opened the cylinder valves first. As a result, the pressure differential across the zone valve prevented opening of the ball valve.

d. Failure of the Emergency Diesel Generator

At 0610, the Emergency Diesel Generator (EDG) automatically started with the loss of the main power supply. A minute later, the EDG automatically shut down. It took ship's crew 25 minutes to diagnose and fix the problem. The shut down was caused by a damaged solenoid valve in the fuel line. Engineers opened the inline bypass valve and power from the EDG was restored.

At 1126, the EDG automatically shut down. It took ship's crew 45 minutes to diagnose and fix the problem. The shut down was due to the result of a coolant problem. Engineer refilled the unit with coolant and power from the EDG was restored.

The EDG failure had minimal impact on the response and firefighting efforts due to battery back-up systems, and the ability of ship's crew to fix the EDG problems in relatively short order.

Review of electronic log books, indicates the EDG was inspected and tested on a weekly basis for approximately 30 minutes. During these tests, the EDG was not carrying an electrical load.

e. Firefighting

1) Firefighting Strategy and Actions

Evaluation of the firefighting effort against the procedures in the SMS and Firefighting SOP revealed the following areas of concern:

1. The fire teams lacked familiarity with the engine room spaces and equipment.
2. Poor isolation of the affected space and maintenance of smoke boundaries.
3. Poor choice of fire extinguishing equipment (portable dry chemical fire extinguishers vs fire hoses)
4. The Captain's decision to ventilate the aft engine room before the fire was fully extinguished.

All of these areas of concern hampered the firefighting effort. Furthermore, the decision to use portable chemical extinguishers and the decision to ventilate the space before the fire was extinguished were contrary to the Firefighting SOP and indicate a fundamental misunderstanding of firefighting strategy and procedures.

2) Firefighting Training

Carnival records indicate that the vessel complied with SOLAS requirements for monthly fire drills. In order to provide training to multiple fire teams, it also appears that more than one fire drill was conducted each month. Fire drills were recorded on a number of documents or forms such as, the on-scene command form, emergency checklists and narrative documents. Based on a review of the records or documentation from drills, the following observations were made:

- The level of documentation for fire drills differed with each drill, and many drills had very little documentation beyond the logbook entry. As such, it is difficult to ascertain what was done during the drill and obtain any meaningful information regarding the quality of the drill.
- Several fire drills lasted less than 30 minutes.
- It appears fire teams conducted drills on the aft mooring deck or in the marshalling area, and not in the actual spaces.
- The roles and responsibilities of the Quick Response Team (QRT) and Fire Teams Charlie and Delta are not defined in the SMS.
- Beyond the announcement and logging of drills, it does not appear that the Captain and bridge crew participated in the fire drills.
- From May to November 2010, there were no fire drills conducted in the engine room.

3. Loss of Power and Propulsion

a. Post-casualty Inspection of Aft Engine Room

Photograph 19 and Photograph 20 show melted synthetic and plastic components where flames were not present. In addition, numerous wire ways and cabling, and switchboard components were damaged, including those from other generators in the forward machinery space which prevented the engineers from regaining primary power to the vessel after the fire was extinguished.

The port main switchboard is supplied power from diesel generators 1 and 2 of the forward engine room and diesel generator 4 of the aft engine room. The starboard main switchboard room is powered by diesel generators 5 and 6 of the aft engine room and diesel generator 3 of the forward engine room. Both main switchboards can be tied together through bus ties. The arrangement allows the continuation of power should one switchboard room and its sub-distributions be disabled. Alternatively, it should allow for limited electrical service if there are casualties in either the forward engine room or aft engine room provided the various wire ways and cabling are not destroyed in the aft engine room.

Due to the extensive damage to cables and wire from the fire, it was not possible to determine the exact cause of the power loss. However, the extent of the fire damage was significant enough to prevent vessel engineers from starting the forward engine room diesel generators and/or closing the appropriate breakers to supply power at the switchboard.

C. CONCLUSIONS

1. Engine Failure

This casualty was initiated by a hydrolock event which resulted in a bend in the B1 connecting rod of DG5. This condition went undetected and eventually led to a fatigue fracture of the B1 connecting rod on November 8, 2010. The fatigue fracture resulted in a loss of lube oil to the A1 cylinder and the destruction of various components of the shared crankshaft bay.

The poor condition of the air cooler on the B side of DG5 contributed to the hydrolock event. Excessive rust particles from the plating that constructed the heat exchanger base and other components at times may have performed like a check valve. When the engine was secured, drainage flow from other operating engine air coolers that did not have excessive corrosion and corresponding blockage, could push past the particles and enter the receiver space of DG 5. When DG 5 was started the nearly 3 bar (43 psi) of air pressure developed by the turbocharger may have partially forced the particles back to the drains until they restricted flow. Fluid could have also accumulated due to a leaking tube or tubes within the heat exchange tube bank. At some point, enough fluid accumulated in the receiver and eventually entered the B1 air intake port.

The poor design of the air cooler system contributed to both the deterioration of the system and the excessive accumulation of fluid in the B side air cooler for DG5. While Carnival had recognized the problem with the air coolers on similar vessels, replaced the air cooler on the Carnival Splendor in July 2010 and took steps to prevent and manage the accumulation of fluid in the air coolers, the lack of formal procedures to document these measures and the poor condition of the air coolers (as observed post-casualty) suggests that these procedures were not routinely followed. Furthermore, the solutions devised after the July 2010 air cooler replacement were short-term fixes which relied on human intervention to manage the accumulation of water in the air cooler vice long-term engineering fixes to prevent the accumulation of fluid in the air coolers.

DG5 was equipped with a slow turn system which should have assisted in the prevention of fluid accumulation in the cylinders as well as the detection of fluid in the cylinders during starting. However, the decision by Carnival to lengthen the slow turn interval from 30 minutes to 2 hours may have made the engine more susceptible to the accumulation of fluid in the cylinders and lessened the likelihood of fluid detection when no slow turn takes place before engine start-up.

2. Fire

As a result of the fatigue fracture of the B1 connecting rod for DG 5, engine components, and fuel and lube oil were ejected from the engine casing and created a pool fire on the deck plates between DG5 and DG6. This initial fire on the deck plates between DG5 and DG6 did not last very long and was likely extinguished by the Hi-Fog system or burned out on its own.

Prior to extinguishment the initial fire ignited cables in the wire ways and bundles causing a deep seeded secondary fire located directly above DG5 and DG6 which would smolder, produce smoke and ignite for hours after the casualty. This secondary fire most likely extinguished itself because of a lack of oxygen when the watertight doors were secured for a few hours during the attempt to use the fixed CO2 system.

3. The Hi-Fog Fire Suppression System

It is likely that the activation of the Hi-Fog system for local protection would have extinguished and/or prevented the spread of the initial pool fire between DG5 and DG6 if the system was activated immediately following the engine failure. As such, the lack of manual activation of the Hi-Fog system by the engineering watchstanders, as well as the resetting of the fire alarm panel by the bridge watchstanders were critical mistakes which allowed the initial fire to burn without impediment for several minutes and propagate to the overhead cable runs.

The Hi-Fog system was designed as a local application system for the protection of the diesel engine and consequently had limited effectiveness in extinguishing the fire in the cable runs because the Hi-Fog nozzles in the vicinity of DG5 and DG6 were positioned below the cable runs.

4. Firefighting

The manual firefighting efforts by the crew were ineffective in extinguishing the fire in the cable runs above DG5 and DG6 for the following reasons:

1. The crew’s lack of familiarity with the engine room hampered fire teams efforts to locate and extinguish the fire, and also allowed for the further spread of both fire and smoke.
2. While the use of portable dry chemical and CO2 extinguishers on the small fire in the cable runs may have temporarily extinguished the fire, the fire was not fully controlled by these agents due to a lack of cooling of the cable conductors which held heat and caused the cable insulation and jacket materials to continue to burn.
3. The poor maintenance of smoke boundaries allowed smoke to spread to adjacent spaces. This hampered efforts to locate the source of the fire while also activating fire/smoke detectors in unaffected spaces.
4. The Captain’s decision to ventilate the space before the fire was fully extinguished allowed the fire to reflash.

The poor maintenance of smoke boundaries allowed smoke to travel outside of the aft engine room. As a result, smoke and fire detectors in adjacent spaces were activated, and subsequently the Hi-Fog system was activated in unaffected machinery spaces.

The Captain’s decision to ventilate the aft engine room before the fire was fully extinguished and to not use water to cool the cables was in violation of the Firefighting SOP.

While it appears that Carnival had met the SOLAS and STCW requirements for the training of crewmembers, the performance of the crew in this instance indicates that the training and fire drills did not sufficiently prepare the crew for this type of contingency. Furthermore, the short duration of the fire drills conducted and the lack of fire drills conducted in the engine room call into question the quality of the fire drill program and the fire drills conducted.

5. The Full Flood CO2 System

The full flood CO2 system failed to operate and thus was ineffective at extinguishing the aft engine room fire.

The problems uncovered by the post-casualty inspection of the CO2 system were significant and should have been revealed by the initial and subsequent inspections by Fincantieri, Carnival, Panama (the flag state) and/or Lloyd's Register (the Recognized Organization acting on behalf of Panama).

6. Loss of Power

The loss of power was the result of the significant fire damage to the wires and cables in the aft engine room.

As the vessel lost power within 9 minutes of the engine failure, the only way to have prevented the loss of power in this instance was to prevent the spread of fire to the cable runs above DG5 and DG6.

Due to the availability of battery back-up power, back-up cylinders to pressurize the Hi-Fog system and the quick response by the crew to restore the EDG, the loss of power from the EDG had minimal effect on the response to the engine room fire.

7. Administrative

There is no evidence of actionable misconduct by any involved parties.

D. RECOMMENDATIONS:

1. Recommend that Carnival Corporation remove the 40-second time delay in the automatic activation sequence for the Hi-Fog system. This should be done in conjunction with recommendation #2 below, which addresses immediate casualty control procedures for engine room fires.

The seconds and minutes following the ignition of a fire are crucial to the firefighting response. As such, failure to take quick and prompt action to extinguish a fire can lead to major, negative downstream effects. In this instance, the delay in the activation of the Hi-Fog system in conjunction with the manual reset of the fire detection system adversely affected system performance and allowed the fire to spread to the overhead cable runs. Had Hi-Fog system been activated promptly vice delayed, the initial fire between DG5 and DG6 may have been contained it is likely that the vessel would not have lost power.

2. Recommend that Carnival Corporation address the conditions listed below in their Safety Management System and/or through improvements to ship systems to eliminate or mitigate risk factors which contributed to this casualty:

a. The corrosion and drainage issues with the air cooler system for all DGs.
b. The problems with the slow turn feature of the DGs. In particular, the effect of increasing the slow-turn interval from 30 minutes to 2 hours on the detection of fluid in engine cylinders.
c. The lack of crew familiarity with immediate casualty control procedures for engine room fires.
d. The lack of crew familiarity with the engine room layout and firefighting strategy and procedures for engine room fires.
e. The problems identified with the CO2 system installation and activation procedures, as well as inspection protocols.
f. The susceptibility of the Carnival Splendor and all Dream class vessels to a complete loss of power due to the design and arrangement of electrical system and components.

3. Recommend that at their next annual inspection Lloyd's Register, as the Recognized Organization acting on behalf of Panama, inspect the CO2 systems onboard all Dream class vessels built in the Fincantieri yard for the installation and operational problems uncovered by this investigation.

The CO2 system is a crucial line of defense in extinguishing an engine room fire, and must be installed and operate properly when needed. As the Dream class vessels are based on the Destiny class vessel and were built in the Fincantieri yard, Destiny class vessels should also be considered for review.

4. Recommend that the Commandant, United States Coast Guard, enhance the current guidelines and procedures for the evaluation of fire drills which are conducted as part of Control Verification Exams for foreign vessels.

Fire drills provide an opportunity for Port State Control Officers (PSCOs) to gain a meaningful assessment of the crew's proficiency in firefighting equipment and procedures, as well as ship familiarity. Currently, Navigation and Vessel Inspection Circular (NVIC) 3-08, NVIC 6-03 Change 2 and NVIC 6-91 provide guidance to Coast Guard PSCOs for the conduct and evaluation of fire drills. While this guidance is still valid, it is very high level and based on guidance from the International Maritime Organization to ship owners and operators that carry out fire drills. As such, this guidance should be enhanced to assist PSCOs in better evaluating fire drills, as well as reviewing of records of past fire drills and training.

5. As the United States representative to the International Maritime Organization (IMO), recommend that the Commandant, United States Coast Guard, advocate for and make a recommendation to the IMO for improved guidance for fire drills onboard all ships subject to the requirements of the International Convention for the Safety of Life at Sea (SOLAS).

Although this casualty illustrates that improved guidance on the conduct and evaluation of fire drills is something that may be necessary, it would be difficult to put this into effective practice through Coast Guard action alone without a parallel effort at the International Maritime Organization (IMO) to improve guidance internationally.