Heeling Accident on M/V *Crown Princess* Atlantic Ocean Off Port Canaveral, Florida July 18, 2006

ACCIDENT REPORT

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Marine Accident Report

Heeling Accident on M/V *Crown Princess* Atlantic Ocean Off Port Canaveral, Florida July 18, 2006

National Transportation Safety Board

490 L'Enfant Plaza, S.W.
Washington, D.C. 20594

National Transportation Safety Board. 2008. ***Heeling Accident on M/V*** **Crown Princess,** ***Atlantic Ocean Off Port Canaveral, Florida, July 18, 2006.*** **Marine Accident Report NTSB/MAR-08/01. Washington, DC.**

Abstract: This report discusses the July 18, 2006, accident on the cruise ship *Crown Princess* in which the vessel heeled at a maximum angle of about 24°, resulting in injuries to 298 passengers and crewmembers. The vessel's second officer, the senior watch officer on the bridge, had disengaged the automatic steering mode of the vessel's integrated navigation system and taken manual control of the steering in an effort to counteract a perceived high rate of turn to port. He turned the wheel first to port and then between port and starboard several times, causing the vessel to suddenly heel and people to be thrown about or struck by unsecured objects. The *Crown Princess* incurred no structural damage, although unsecured interior items were damaged.

The Safety Board's investigation of the accident identified the following safety issues: actions of the captain, staff captain, and second officer; training in the use of integrated navigation systems; reporting of heeling incidents and accidents; and emergency response following severe incidents.

On the basis of its findings, the Safety Board made recommendations to the U.S. Coast Guard, to the Cruise Lines International Association, and to SAM Electronics and Sperry Marine (manufacturers of integrated navigation systems).

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Contents

Acronyms and Abbreviations

AIS	automatic identification system
ARPA	automatic radar plotting aid
CFR	*Code of Federal Regulations*
CLIA	Cruise Lines International Association
COTP	Captain of the Port
ECDIS	electronic chart display and information system
GPS	global positioning system
ICCL	International Council of Cruise Lines
IBS	integrated bridge system
IMAC	integrated monitoring, alarm, and control
INS	integrated navigation system
ISO	International Organization for Standardization
LORAN	LOng RAnge Navigation
MSC	Maritime Safety Committee
NACOS	Navigation and Command System
QE2	*Queen Elizabeth 2*
SOLAS	International Convention for Safety of Life at Sea
STCW	Standards of Training, Certification, and Watchkeeping for Seafarers
STW	Standards on Training and Watchkeeping
VDR	voyage data recorder

Executive Summary

On July 18, 2006, the cruise ship *Crown Princess*, which had been in service about a month, departed Port Canaveral, Florida, for Brooklyn, New York, its last port on a 10-day round-trip voyage to the Caribbean. Slightly more than an hour after departing, while on a heading to intersect its track to Brooklyn, the vessel's automatic steering system began a turn to port. In an effort to counter the effects of a perceived high rate of turn, the second officer, the senior watch officer on the bridge, disengaged the automatic steering mode of the vessel's integrated navigation system and took manual control of the steering. The second officer turned the wheel first to port and then from port to starboard several times, eventually causing the vessel to heel at a maximum angle of about 24° to starboard. The heeling caused people to be thrown about or struck by unsecured objects, resulting in 14 serious and 284 minor injuries to passengers and crewmembers. The vessel incurred no damage to its structure but sustained considerable damage to unsecured interior components and to cabinets and their contents.

The National Transportation Safety Board determines that the probable cause of the *Crown Princess* accident was the second officer's incorrect wheel commands, executed first to counter an unanticipated high rate of turn and then to counter the vessel's heeling. Contributing to the cause of the accident were the captain's and staff captain's inappropriate inputs to the vessel's integrated navigation system while the vessel was traveling at high speed in relatively shallow water, their failure to stabilize the vessel's heading fluctuations before leaving the bridge, and the inadequate training of crewmembers in the use of integrated navigation systems.

The Safety Board's investigation of the accident identified the following safety issues:

- Actions of captain, staff captain, and second officer.
- Training in use of integrated navigation systems.
- Reporting of heeling incidents and accidents.
- Emergency response following severe incidents.

As a result of its investigation, the Safety Board makes recommendations to the U.S. Coast Guard, to the Cruise Lines International Association, and to SAM Electronics and Sperry Marine (manufacturers of integrated navigation systems).

Factual Information

Accident Narrative

At 1406[1] on July 18, 2006, the Bermuda-registered cruise ship M/V *Crown Princess* (figure 1), operated by Princess Cruises, departed Port Canaveral, Florida, for Brooklyn, New York, on the last leg of a 10-day round-trip voyage to the Caribbean (figure 2). It was the vessel's fourth voyage after being christened in Brooklyn on June 14. A total of 4,545 persons were on board—3,285 passengers and 1,260 crewmembers. A Florida state harbor pilot had the conn—that is, was in control of the ship's movement.[2] The ship's captain, staff captain (second in command on Princess Cruises vessels), relief captain, second officer, two fourth officers, and two helmsmen were also on the bridge.[3] According to the captain, the wind was light, the sky was clearing, visibility was good, and the sea state was "slight" as they left Port Canaveral.

At 1437, according to the ship's log, the pilot left the bridge, disembarking soon afterward, and the captain assumed the conn. The captain then began increasing the ship's speed in increments of 10 propeller revolutions per minute. At 1456, as recorded on the vessel's VDR,[4] the captain told the chief engineer, "We want to go as fast as we can for the time being for the weather." The staff captain told investigators that the captain was hoping to "get ahead of" a developing storm along the vessel's route. Around the same time, the captain shifted control of the engines to the engineroom. The chief engineer, now in direct control of the vessel's propulsion system, continued to increase the ship's speed.

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[1] Times in this report are eastern daylight time according to the 24-hour clock. Times on the vessel's various clocks, logs, and other recording devices (such as onboard cameras) differed. Investigators' efforts went into determining the time a particular event occurred. The approach was to synchronize all times with those recorded by the vessel's voyage data recorder (VDR) from a global positioning system (GPS) receiver. VDR time was then converted to local time (eastern daylight time) in the accident area.

[2] A Florida-licensed state pilot is required for all foreign-registered vessels in foreign trade and for all vessels over 500 gross tons operating into or out of Port Canaveral, unless specifically exempted by the port director.

[3] The *Crown Princess* was staffed with more than one second officer and more than one fourth officer. The report refers only to those on watch during the accident sequence. One of the fourth officers on the bridge was observing. The relief captain was on board because he was scheduled to relieve the captain at the ship's next port of call (Brooklyn). See "Personnel Information" section for details about the watch officers.

[4] The VDR continuously recorded audio data from the bridge, in addition to collecting data related to the ship's operation. For more information, see "Voyage Data Recorder" section. VDR data from the *Crown Princess* are plotted in appendix B. A transcript of the vessel's VDR audio recording is found in appendix C.

From the dock to a point beyond where the pilot disembarked,[5] the bridge crew controlled the vessel's steering manually. At 1501, on orders from the captain, the crew engaged the trackpilot, the autopilot function of the vessel's integrated navigation system (INS).[6] The INS on the *Crown Princess* was a NACOS (Navigation and Command System) manufactured by SAM Electronics of Hamburg, Germany.[7]

The crew set the course to 100° in heading mode, one of three available steering modes in the trackpilot.[8] According to the ship's log, the seas were calm and there was a gentle breeze from the northeast. Shortly after the course was set, the captain noticed that the vessel's heading was fluctuating, and he reviewed the trackpilot settings (table 1). According to the second officer, the course fluctuations were causing "quite an excessive rate of turn." The second officer said that he asked the captain, "Would you like to go back into hand steering?" and the captain said, "No, I've got the conn."[9]

Figure 1. The *Crown Princess* sailing past the Statue of Liberty as it arrived in New York from the shipyard in Italy. The cruise ship was nearly 1,000 feet long, had 19 decks, and could carry more than 4,000 people. (Photo courtesy Princess Cruises)

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[5] Pilots ordinarily board and disembark about 1 mile southeast of whistle buoy 3 in Canaveral Harbor (National Oceanic and Atmospheric Administration, National Ocean Service, *United States Coast Pilot*, vol. 4 [Atlantic Coast: Cape Henry, VA, to Key West, FL], 2004, p. 419).

[6] The International Maritime Organization, a specialized agency of the United Nations, defines an INS as follows: "A combination of systems which are interconnected in order to allow centralized access to sensor information or command/control from workstations, with the aim of increasing safe and efficient ship's management by suitably qualified personnel." (International Maritime Organization document STW 36/3/1 "Validation of Model Training Courses," August 12, 2004, p. 27.) See "Integrated Navigation Systems" section for more information.

[7] SAM Electronics, formerly STN Atlas Marine Electronics, is a wholly owned subsidiary of L3 Communications Corporation, New York.

[8] The other steering modes were course mode and track mode. For details, see "Integrated Navigation Systems" section.

[9] The second officer's statement was made during an investigative interview. Investigators were unable to verify the exchange on the VDR audio recording from the bridge. See "Voyage Data Recorder" section for a discussion of the limitations of the VDR audio recording.

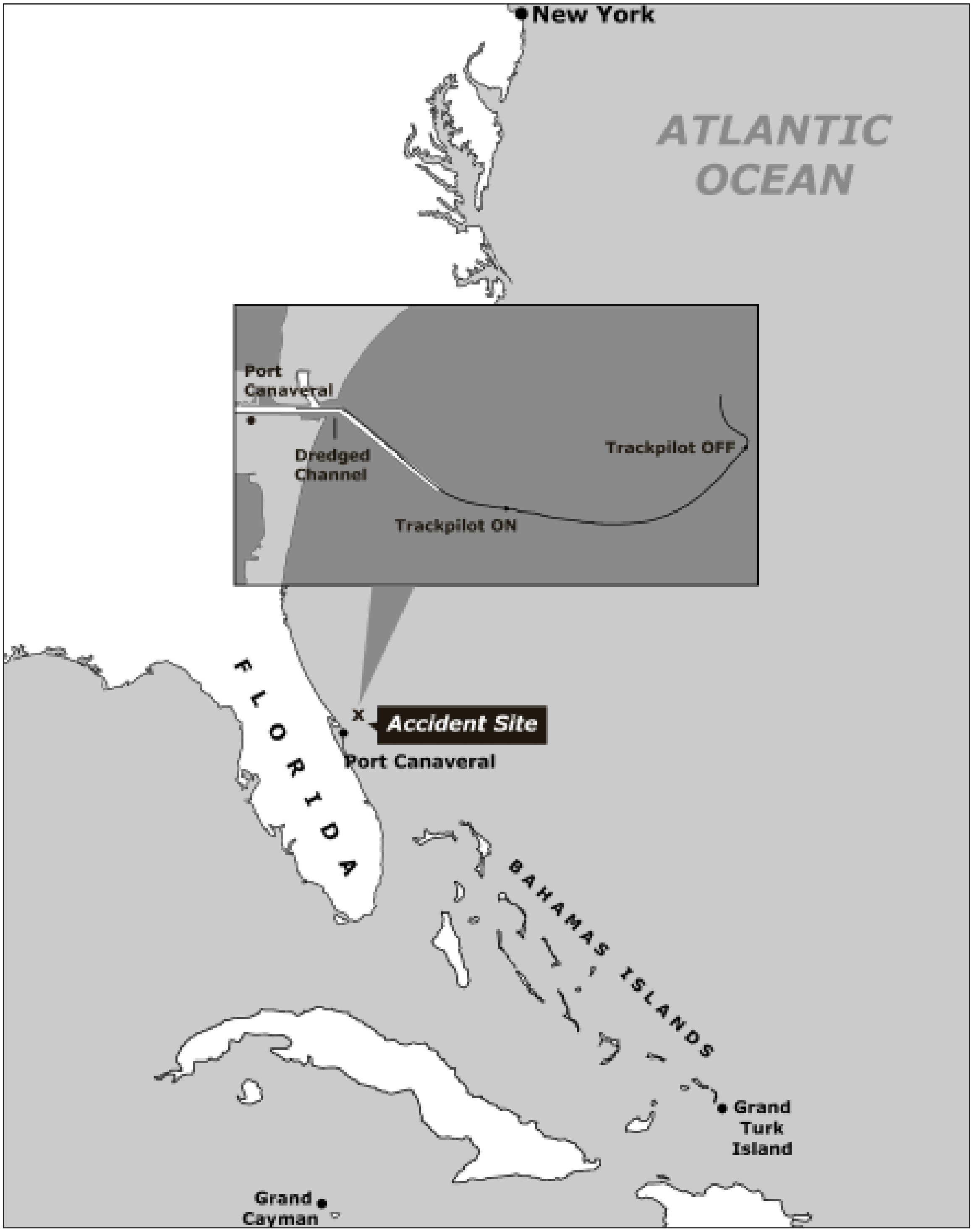

Figure 2. The *Crown Princess* was returning to New York from a Caribbean cruise with ports of call at Grand Turk Island, Ocho Rios, Jamaica, and Grand Cayman Island when it heeled about 10 nautical miles east of Port Canaveral, Florida. Inset shows the ship's track from Port Canaveral to the accident site. Water in the area was relatively shallow, about 26 feet below the vessel's keel.

Table 1. Sequence of events while the trackpilot was engaged.

Time	Event
1501	Crew shifts steering from manual to trackpilot
1503	Captain notices heading fluctuations
1505:06	Trackpilot rudder limit alarm sounds
1505:38	Captain: “We’re wandering all over the place”
1506:09	Captain: “At the moment she is not responding other than 10 degrees at a time”
1506:27	Rudder limit alarm sounds
1507:07	Staff captain increases rudder limit to 10°
1508:00	Rudder limit alarm sounds
1512	Staff captain: “Is it okay now?” Captain: “No”
1513	Staff captain discusses trackpilot settings with captain
1513	New course input to trackpilot, vessel begins turn to port
1514:33	Captain: “Stay in that turn . . . OK, we’ll run like that”
1518:14	Captain to second officer: “Okay, you got the conn”
1522	Heading approaches ordered course of 040°, again begins to fluctuate
1522	Captain and staff captain leave bridge
1523	Relief captain leaves bridge

At 1505:06, during the second heading fluctuation, when the rate of turn reached 9° per minute, the trackpilot’s rudder limit alarm sounded.[10] According to the operating instructions for the NACOS,[11] the rudder limit alarm indicates the following:

> The set rudder limit value has been reached; with this rudder limit, the maneuver cannot be performed without a deviation, or, the present rudder angle lies outside the rudder limit. Remedy:
>
> - Increase the rudder limit,
> - Wait until the rudder angle becomes less than the rudder limit, or
> - Switch over to manual steering.

[10] The rudder limit was a trackpilot function that the crew could set to limit the extent of rudder movement.

[11] SAM Electronics, *Operating Instructions*: *Radarpilot 1100*, *Chartradar 1100*, *Conningpilot 1100*, item ED 3051 G 032 (revision 2005-01), p. 268. International Electrotechnical Commission standard IEC 60945 requires manufacturers to provide crew operating and service manuals. The NACOS operating manual for crewmembers was 293 pages long, divided into sections for radar functions, automatic identification system, conning displays, trackpilot functions, VDR, alarms, and care and maintenance. Instructions related to the trackpilot covered operational and steering modes, definitions of terms, data displays, and adapting the trackpilot settings to actual states such as weather. A separate, later section included 35 trackpilot alarms in a listing of all alarms to the operator.

After the alarm sounded, the captain called the staff captain over and said, "We're wandering all over the place . . . we put her into NACOS-1."[12] At 1506:09, the captain said, "At the moment she is not responding other than 10 degrees at a time." At 1506:27, the rudder limit alarm sounded again. The staff captain checked the INS settings. He told investigators that the rudder limit was set at 5°. VDR data show that the vessel's speed was about 19 knots at the time.

About 1507, the staff captain increased the rudder limit from 5° to 10°. The staff captain later explained to investigators:

> . . . you exceed this alarm of too much [rudder] and with basically 5 degrees [of rudder limit] set, the ship cannot go back on track within a certain time . . . so I intervened with the captain still having the conn and increased the rudder limit up to 10 and . . . we regained the intended heading that he wanted.

The staff captain further explained:

> To increase the rudder limit, it doesn't really mean . . . that the system will apply ten degrees of rudder. Normally, that gives us more allowance and a little bit more faster response . . . but, of course, it doesn't mean that by setting the [rudder] limit that the limit is used constantly. The limit is only there if there is a need for using it by the system. . . . Since you are in heading mode, it doesn't really make a difference because this applies only when you move from heading or course mode down to track mode.[13]

The staff captain added that he was not aware of guidance from the cruise line or the manufacturer on when to change the rudder limit.[14]

At 1508, the rudder limit alarm sounded again. At 1513, the vessel began a turn to port to intersect the first plotted track to New York. The course change, from a heading of 100° to a heading of 040°, was executed through several small adjustments to the autopilot's set heading. The vessel's speed had now reached 20 knots. The captain directed the second officer: "Stay in that turn . . . OK, we'll run like that." The captain then asked the second officer for the heading of the next navigation track.

At 1518:14, the captain turned the conn over to the second officer. About 1519, the vessel's heading again began to fluctuate around the set heading. The captain and staff captain left the bridge at 1522, and the relief captain left about a

[12] NACOS-1 was the Princess Cruises term for trackpilot 1. The term is not consistent with the SAM Electronics designations. Its origin was not determined.

[13] See "Integrated Navigation Systems" section.

[14] General instructions for setting the rudder limit were given in the SAM Electronics *Operating Instructions*, "Trackpilot Functions," section 26.2, "Adaptation to Suit the Weather and the Type of Waterway," as follows: "The rudder limit value should be reduced if a constant course is to be steered for a long time on the open sea or if, for example because of the loading state or other reasons, large angles of the rudder are not permitted. In coastal approaches, the rudder limit value must be suitably increased so that the ship can turn with a small radius or can be controlled at low speed" (p. 208).

minute later. The second officer, the two fourth officers, and the two helmsmen (as lookouts) remained on the bridge.

About 1523, the vessel reached a turn rate of about 10° per minute to starboard. The turn then shifted to port, and the rate of turn reached nearly 20° per minute. The rate-of-turn indicator (figure 3) displayed red for turns to port, green for turns to starboard. The indicator did not show turn rates beyond 30° per minute in either direction, although a turn rate of any size was displayed digitally next to the indicator. The second officer told investigators that shortly after he took the conn, the rate-of-turn indicator "was a bright color red . . . my eyes were instantly drawn to it."

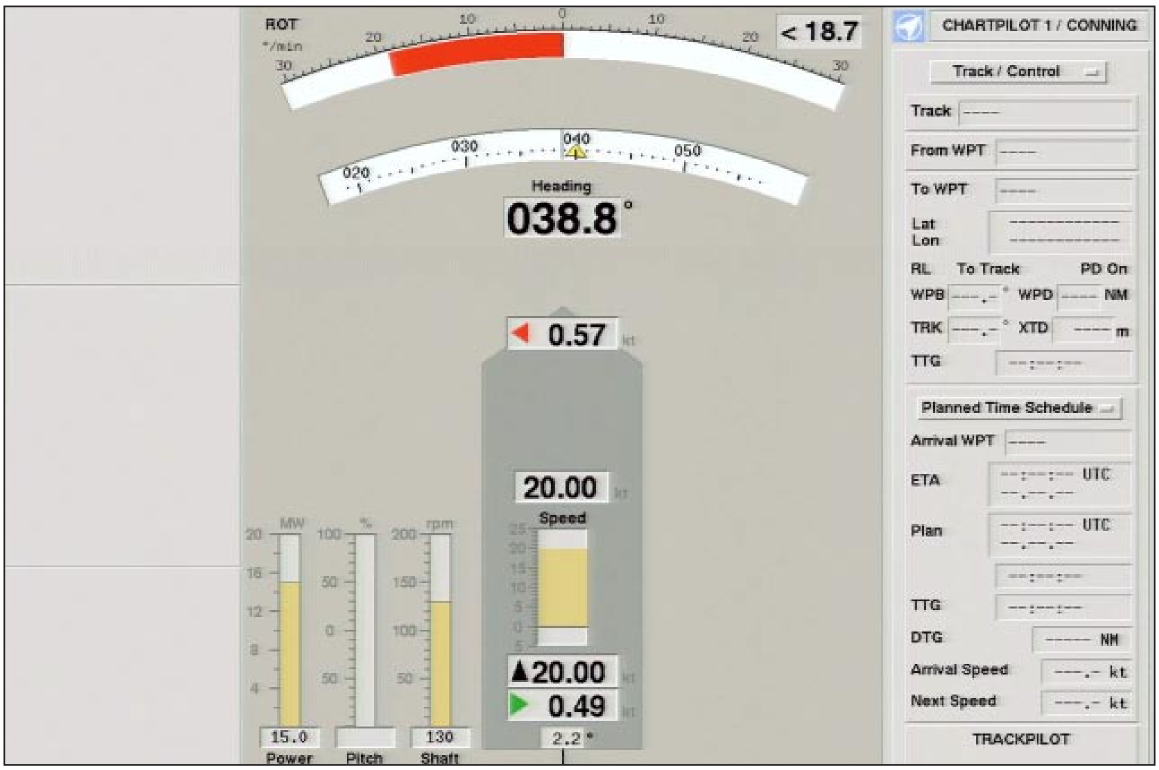

Figure 3. Trackpilot display on the *Crown Princess*. The rate-of-turn indicator is at the top, abbreviated ROT. The highest rate of turn displayed in either direction on that indicator was 30° per minute. The digital display on the right above the indicator could show any rate of turn. The rate of turn displayed here is 18.7° to port.

At 1524, the second officer disengaged the trackpilot and, because he was closer to the wheel than either of the helmsmen, took manual control of the steering.[15] The second officer told investigators, "I just saw the rate of turn and instinct took over, I thought . . . we're going to be swinging to port really fast here and I've got to get hand steering . . . [to] try to stop the swinging." VDR data show that for about

[15] The trackpilot was disengaged during the entire accident sequence. Disengaging the trackpilot also disengaged the rudder limit setting and the rudder economy setting (described later in the report).

a minute after disengaging the trackpilot, the second officer repeatedly turned the wheel back and forth between port and starboard (table 2). VDR data also show that after the second officer disengaged the trackpilot, the speed at which he moved the wheel exceeded the rudders' ability to respond to his commands.[16] Thus, the rudders lagged the wheel inputs. The vessel's response lagged the steering inputs even farther (see "Vessel Dynamics" section for details).

Table 2. Sequence of events after the second officer disengaged the trackpilot and began steering manually. Wheel commands indicate manual inputs to vessel steering, not the resulting rudder movement.

Time	Event
1524:05	Second officer disengages trackpilot, switches to manual steering mode
1524:11	Wheel command: port 10°
1524:18	Wheel command: starboard 10°
1524:20	Fourth officer: "Port ten"
1524:21	Second officer: "I know"
1524:22	Fourth officer: "Port ten . . . man you are port ten, you are port ten"
1524:23	Second officer: "Yeah, I am coming over to starboard"
1524:26	Wheel command: port 30°
1524:26	Warning sound (continues for 1 min 49 sec)[a]
1524:28	Fourth officer: "You are at port ten"
1524:29	Second officer: "Yeah, I am coming over . . ."
1524:36	Warning sounds (last less than 1 sec)
1524:42	Wheel command: starboard 10°
~1524:40-1525[b]	Captain, staff captain, and relief captain return to bridge
1524:43	Relief captain: "Reduce the speed, reduce the speed"
1524:45	Wheel command: starboard 30°
1524:48	Warning sound (continues for 1 min 6 sec)[a]
1524:49	Wheel command: port 35°
1524:49	Second officer pulls back on throttle, orders 0 revolutions per minute
1524:50	Wheel command: port 45°
1524:59	Wheel command: starboard 5°
1525:00	Wheel command: 0° (midships)
1525:00	Captain: "Stop the engines, stop the engines, stop the engines"
1525:34	Wheel command: starboard 45°
1526:20	All audible warnings stop

[a] Investigators could not determine which device sounded the warning.

[b] The officers arrived back on the bridge over a period of several seconds. Time was estimated from the VDR audio record and interview statements.

[16] The *Crown Princess* was equipped with two rudders. See "Vessel Information" section.

The second officer first turned the wheel to port 10°. He told investigators that he had meant to turn to starboard, but instead went to port. He was unable to explain his action. Eight seconds after turning to port, he turned the wheel to starboard 10°. The fourth officer on watch immediately alerted the second officer that the rudders were at port 10°. (Although the second officer had already turned the wheel to starboard, the rudders required several seconds to respond.[17]) The second officer acknowledged the fourth officer's statement, saying, "Yeah, I am coming over to starboard," but he then turned the wheel to port 30°.

Several seconds after being reminded, "You are at port ten," and after again telling the fourth officer that he was "coming over," the second officer turned the wheel to starboard 10°. The VDR recorded numerous audio alerts around this time, along with the sound of objects falling to the bridge deck. The second officer told investigators, "I've never seen a ship lean over that far before." He further stated,

> I don't remember just like moving the wheel around and I can't say which way I was doing it and how much I was doing it because by then, the ship was leaning over so much that I was just basically trying to do anything that I thought was going to assist in getting the ship upright.

The captain, staff captain, and relief captain ran to the bridge, arriving over a period of several seconds. The relief captain, who arrived first, ordered, "Reduce the speed, reduce the speed." Two seconds later, the second officer turned the wheel to starboard 30°, followed 4 seconds later by a turn to port 35°. The second officer then pulled back on the throttle, ordered zero revolutions per minute,[18] and turned the wheel to port 45°. Ten seconds later the captain ordered, "Stop the engines, stop the engines, stop the engines." By that time, the wheel had been turned to midships and the staff captain had arrived.

About 1525, the vessel reached a maximum angle of heel of about 24° to starboard (see "Heel Angle Determination" section). At the same time, the vessel's rate of turn reached a maximum of 80° per minute. Immediately after the vessel reached its maximum heel, the staff captain turned the wheel hard to starboard. All audible warnings ceased at 1526:20, and the vessel returned to even keel about 1527. By then, its speed had slowed to 12 knots.

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[17] As explained in the "Vessel Information" section, either 14 or 28 seconds were required for the steering gear to move a rudder from hard over in one direction to hard over in the opposite direction, depending on how many rudder pumps were operating. According to the International Convention for Safety of Life at Sea (SOLAS) 1974, as amended, chapter II-1, regulation 29, "Steering Gear," section 3.2: "The main steering gear and rudder stock shall be capable of putting the rudder over from 35° on one side to 35° on the other side with the ship at its deepest seagoing draught and running ahead at maximum ahead service speed and, under the same conditions, from 35° on either side to 30° on the other side in not more than 28 s [seconds]." The rudders on the *Crown Princess* moved about 3° per second.

[18] As noted earlier, the captain had passed engine control to the engineroom. Because the bridge did not have direct control of the engines when the second officer issued the engine order, the engine speed was not immediately reduced.

Princess Cruises, like other cruise lines, employed dedicated observers on both bridge wings[19] to monitor the balconies for fire. After the accident, the captain asked the observers whether they had noticed any passengers or crewmembers fall overboard. They told him that they had not. The captain decided against mustering the passengers because of the information from the observers and his sense that the passengers were "in shock" as a result of the accident.

Responses to a Safety Board questionnaire, which was sent to most passengers who were evacuated to hospitals and 200 other passengers selected at random,[20] describe the passengers' reactions to the ship's sudden heeling. Passengers in cabins saw televisions fall from their bases and tables and chairs move rapidly about the cabins, while those in public areas observed similar occurrences for both light and heavy objects. A 54-year-old man who was entering the buffet on the fifteenth deck wrote,

> They had reset the tables for dinner with wineglasses and china. The ship began to list to the starboard. The glasses and plates began to slide off the tables and I saw my sister-in-law fly off her chair. I fell off my chair, [I] tried [to] grab my wife and slid across the room. My sister-in-law seriously injured her hand and was taken off by ambulance. My son jumped off his bunk bed and hurt his knee. I was scraped and hurt my hamstring.

During the accident, water, people, and objects spilled out of the ship's swimming pools. A 44-year-old woman, who was near one of the pools at the time of the accident, reported:

> I first realized something was wrong when I felt the boat tilt and it was uncomfortable to stand upright. We (my husband and I) noticed the water slowly coming out of the pool and drinks on tables falling. A second tilt occurred and we moved quickly towards the railing for support, and watched [as] "a small wave" of water, people, and belongings moved out towards the starboard side. The tilting stopped for a few seconds and then a much greater tilt occurred with a "large wave" [spilling] out knocking over people, chairs, tables, and miscellaneous belongings.

The captain made several announcements over the vessel's public address system after the event. Following the first announcement, he asked the senior physician on the vessel about the condition of any injured passengers. She recommended, and he agreed, to return to port to enable those who needed more extensive medical treatment than available on the ship to be taken to hospitals. The *Crown Princess* returned to Port Canaveral and docked with gangways down at 1836.

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[19] The bridge wings were enclosed extensions of the bridge on either side.

[20] Of the 278 questionnaires that were sent, 117 were completed and returned to the Safety Board.

Injuries

The type and number of recorded injuries to passengers and crewmembers in the accident are listed in table 3. Princess Cruises provided investigators with the names of 239 passengers who sought medical treatment, along with such information as cabin number, sex, age, date of birth, triage tag number, hospital, and injury description. Many names did not have entries for triage tag number or injury description. Princess Cruises also provided investigators with a list of 57 crewmembers who received injuries during the accident. The injuries were similar to those of the passengers.

Table 3. Injuries sustained in the *Crown Princess* accident.

Injury Type	Crew	Passengers	Total
Fatal	0	0	0
Serious	0	14	14
Minor	57	227	284
None	1,203	3,044	4,247
Total	1,260	3,285	4,545

NOTE: Title 49 *Code of Federal Regulations* (CFR) section 830.2 defines a fatal injury as any injury that results in death within 30 days of an accident. It defines serious injury as that which requires hospitalization for more than 48 hours, commencing within 7 days from the date the injury was received; results in a fracture of any bone (except simple fractures of fingers, toes, or nose); causes severe hemorrhages, nerve, muscle, or tendon damage; involves any internal organ; or involves second- or third- degree burns, or any burns affecting more than 5 percent of the body surface. A 67-year old male passenger on the vessel died 37 days after the accident, according to his death certificate, as a result of sepsis and pneumonia, secondary to metastatic preexisting lung cancer.

Listed injuries included sore extremities, minor bruising, scratches, lacerations needing stitches, broken bones, and chest pains. Minor injuries such as scratches and bruises were not recorded. A medically trained passenger who assisted vessel medical personnel in the dining facility, designated as a medical center in the event of a large-scale emergency, estimated that over 125 passengers were treated there. Investigators determined the number of injured passengers based on information provided by Princess Cruises and on records of shoreside hospitals and fire and rescue agencies.

The Safety Board obtained 57 medical records of passengers treated at local hospitals, 10 describing injuries considered serious. They included a passenger with a dislocated shoulder, a passenger with muscle tissue lacerations, and passengers with fractures to the ribs, humerus, wrist, or foot. The remaining passengers sustained minor injuries such as contusions, lacerations, sprains, strains, or reported pain. Injuries resulted primarily from people striking objects on the vessel or objects on the vessel striking people. An additional four seriously injured passengers were identified from the passenger questionnaires; no medical records were received for those passengers.

Personnel Information

General

The captain was in command of the *Crown Princess*. The staff captain reported to the captain, and the senior first officer and the other first officer reported to the staff captain. The senior second officer and other second officers reported to the first officers, and the third and fourth officers reported to the second officers.

Captain

The captain, a United Kingdom national aged 54 at the time of the accident, joined P&O Cruises[21] as a third officer in 1973 after graduating from a British maritime academy, and served on both passenger and cargo vessels. From 1977, he worked exclusively on passenger vessels. The first vessel on which he served as captain was the *Island Princess*, in 1997. In 1999, he was captain of the *Grand Princess*, the first of the current generation of large vessels he commanded. He was the first captain of the *Crown Princess,* from its delivery voyage through the time of the accident. All performance appraisals in his personnel file were positive.

According to Princess Cruises records, the captain completed courses in automatic radar plotting aids (ARPA) in September 1985, a 3-day computer chart systems class in July 1997, a 3-day course in the NACOS INS at the SAM Electronics facility in Germany, also in July 1997, and a course in electronic chart display and information systems (ECDIS)[22] in November 2001. In addition, he completed a 5-day course in bridge resource management in December 1995.

Three nights before the accident, the captain went to sleep at 2100 and arose at 0500. Two nights before the accident, he went to sleep at 2200 and arose at 0600. The night before the accident, he went to sleep at 2200, and he awoke at 0500 the day of the accident.

Staff Captain

The staff captain, an Italian national aged 43 at the time of the accident, graduated from an Italian maritime academy in 1981. He spent the next 10 years on various cargo vessels, including tankers, bulk carriers, refrigerated cargo vessels, container vessels, and general cargo vessels. He joined Princess Cruises

[21] As explained in the "Operational and Management Information" section, P&O Cruises, like Princess Cruises, became a subsidiary of Carnival Corporation.

[22] ECDIS is a navigation system that combines electronic navigation information, including vessel position, waterway information, and other critical parameters, into a single navigation display that can be used in lieu of paper navigation charts.

in March 1991 as a second officer and had served as a deck officer exclusively on its vessels since. The performance appraisals in his Princess Cruises personnel file were positive.

According to Princess Cruises records, the staff captain completed a 5-day course in bridge resource management in January 1995, a course in spoken English,[23] and a 4-day course on the NACOS system at the SAM Electronics facility in Germany in 2002. The staff captain told investigators that he regularly availed himself of opportunities to learn about the NACOS INS:

> I've done some personal training, including the various [INS] set ups on the new ships with . . . electronics technicians. Every time that . . . a new updated version of generation of [INS] systems [was installed], because I'm very keen with electronics, I always tend to have some more updates. So, continually I've done three new ships in a row, the *Coral Princess*, the *Diamond Princess*, and this is the other one. I think I received probably extra training from SAM Electronics.

Three nights before the accident, the staff captain went to sleep at 2200 and awoke at 0600. Two nights before the accident, he went to sleep at 2200 and awoke at 0700. The night before the accident, he went to sleep at midnight and awoke at 0500.

Second Officer

The 27-year-old second officer, a United Kingdom national, was enrolled in a British maritime institute from 1996 through 2000. While a student, he served as a cadet on Cunard Lines vessels,[24] receiving positive appraisals of his performance. In June 2000, on graduating from the institute, he joined Cunard Lines as a third officer and served on passenger vessels through the time of the accident. Performance appraisals in his personnel file were generally positive.

After joining Cunard Lines, the second officer alternated between the *Queen Elizabeth 2* (*QE2*), the *Vistafjord* (later rechristened the *Caronia*), and various Seabourn vessels.[25] He served on the *QE2* until April 2006 and then went on leave. On his return to duty in June, he served on the *Diamond Princess* for 2 ½ weeks, then reported to the *Crown Princess* on July 7, 2006. He spent 5 days familiarizing himself with the vessel, then assumed the responsibilities of second officer.

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[23] Princess Cruises required officers who were not native speakers to demonstrate proficiency in the English language. Students had to pass an examination in spoken English to earn a certificate of proficiency after taking this course.

[24] The operations of Cunard Lines, which became a subsidiary of Carnival Corporation, were combined with those of Princess Cruises and P&O Cruises, also acquired by Carnival Corporation. See "Operational and Management Information" section.

[25] Seabourn was part of the Princess/Cunard/P&O organization.

Princess Cruises records indicate that the second officer completed a 5-day bridge resource management course in the United Kingdom in June 2001 and a 3-day course on the NACOS INS in July 2004, in Germany, conducted by SAM Electronics. The first vessel on which the second officer served that had a NACOS INS was the *Diamond Princess*. However, he told investigators that because the vessel operated almost entirely in Alaskan waters, where manual steering predominated, the INS "wasn't really utilized" and he did not interact with an INS until joining the *Crown Princess*. He also said that the *QE2* did not have a NACOS.[26]

In the 3 days before the accident, the second officer was on watch from midnight to 0400 and from noon to 1600. He then slept from 0430 to 1100, except on the day before the accident, when he slept from 0430 to 1000 and from 1730 to midnight. He slept again the morning of the accident from 0430 to 1100.

Vessel Information

History and Construction

The *Crown Princess* was constructed in Monfalcone, Italy, by Fincantieri Cantieri. The manufacturer conducted sea trials of the vessel in March 2006. The trials included maneuvering tests, inclining (stability) tests, checks of mechanical and electrical systems, and checks of NACOS components. The vessel sailed to Brooklyn, New York, and entered service there in June.

The gross tonnage of the *Crown Princess* was 113,561. The vessel had 19 decks and was 947 feet long, 195 feet high, and had a beam of 159 feet including the bridge wings (the beam was 118 feet without considering the bridge wings). The vessel's maximum speed was 21.5 knots. Its forward draft on the day of the accident was 8.36 meters (27.4 feet), and its aft draft was 8.76 meters (28.7 feet).

Classification and Inspection

The *Crown Princess* was registered in Bermuda. The ship was dual-classed by Lloyd's Register and Registro Italiano Navale. The *Crown Princess* was inspected by its flag-state authority, the Bermuda Maritime Administration. Under the control verification system, the U.S. Coast Guard examined the vessel and issued a passenger vessel certificate of compliance.[27]

[26] According to SAM Electronics, the QE2 was retrofitted with a NACOS 35-4 INS in 2004.

[27] The Coast Guard's control verification program was established to monitor the safety of foreign-flag vessels that embark passengers from U.S. ports. Vessels are subjected to initial, annual, and quarterly examinations. A passenger ship control verification certificate is issued on satisfactory completion of the annual examination, which includes tests of emergency systems as well as observation and evaluation of crew actions and of communication dealing with emergency situations (U.S. Coast Guard Office of Marine Safety, Security and Environmental Protection, "Report of the Cruise Ship Safety Review Task Force," October 31, 1995 <www.uscg.mil/hq/g-m/nmc/pubs/studies/pas_vsl.htm>).

Propulsion and Steering

The *Crown Princess* was powered by four V-16 and two V-12 Wartsila ZA40S diesel engines that provided power through two 19-megawatt Siemens electric propulsion motors to two fixed-pitch, six-bladed propellers. The two rudders[28] were capable of being turned a maximum angle of 45° but were limited to 35°.[29] Each rudder had two pumps, only one of which operated while the ship was at sea. With one pump operating, 28 seconds were required for the steering gear to move a rudder from hard over in one direction to hard over in the opposite direction. Half that time, or 14 seconds, was needed with both pumps operating. The port and starboard rudders were synchronized, so that the same rudder order from the bridge control system went to each steering gear unit.

The *Crown Princess* was equipped with a SAM Electronics NACOS 65-5. In the SAM Electronics numbering system, the first two digits refer to the configuration of components in the system, while the third refers to the particular NACOS generation.[30] NACOS generation 5 was the most modern NACOS equipment at the time the *Crown Princess* was launched.

The vessel's steering gear units were controlled through one of two electronic steering control systems on the bridge. The first, a Sperry Marine Navipilot 4000, was a basic heading control system or autopilot. Sperry Marine also supplied the manual steering-control system. The second was the SAM Electronics trackpilot system. A steering mode selector switch was located on the bridge center control console. In general, the trackpilot was used mostly in open waters, with manual steering normally used when arriving to and departing from port or in pilotage waters. Princess Cruises allowed the officer on watch to select the steering mode (see "Operational and Management Information" section).

Voyage Data Recorder

As required by SOLAS 1974, as amended, the *Crown Princess* was equipped with a VDR.[31] The ship's VDR, model VER3000 manufactured by Broadgate Ltd., recorded inputs from 9 audio channels, 16 data channels, and a video source (ARPA radar). The recording period was 12 hours, after which the data were recorded over. The data were retained in a hard disk drive that was removed after the accident and taken to the Safety Board's recorder laboratory in Washington,

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28 The rudders were of the compensated spade type. *Spade* refers to the rudder shape. *Compensated* means that part of the blade area was forward of the stock or pivot point.

29 After the ship reached 5 knots, the rudders were limited to 35° of motion in either direction by a relay in the steering control.

30 See "Integrated Navigation Systems" section.

31 SOLAS chapter V, regulation 20, requires passenger ships constructed on or after July 1, 2002, to carry VDRs. The VDR on the *Crown Princess* met the requirements of International Maritime Organization resolution A.861 (20) and International Electrotechnical Commission performance standards for shipboard voyage data recorders, as listed in IEC 61996.

DC. A simplified schematic of a representative VDR system architecture is shown in figure 4. The schematic is similar to, but does not match, the architecture of the VDR installed on the *Crown Princess*.

VDR audio data were recorded by eight microphones on or near the ship's bridge and from transmissions and receptions on channel 16 of the ship's VHF transceiver.[32] Safety Board investigators characterized the quality of the audio recording as "fair."[33] The size of the bridge made it possible for crewmembers to converse too far from any of the microphones for their voices to be recorded accurately. Princess Cruises personnel told investigators that they were researching options available to improve the quality of the recordings, which included seeking the advice of professional audio engineers.

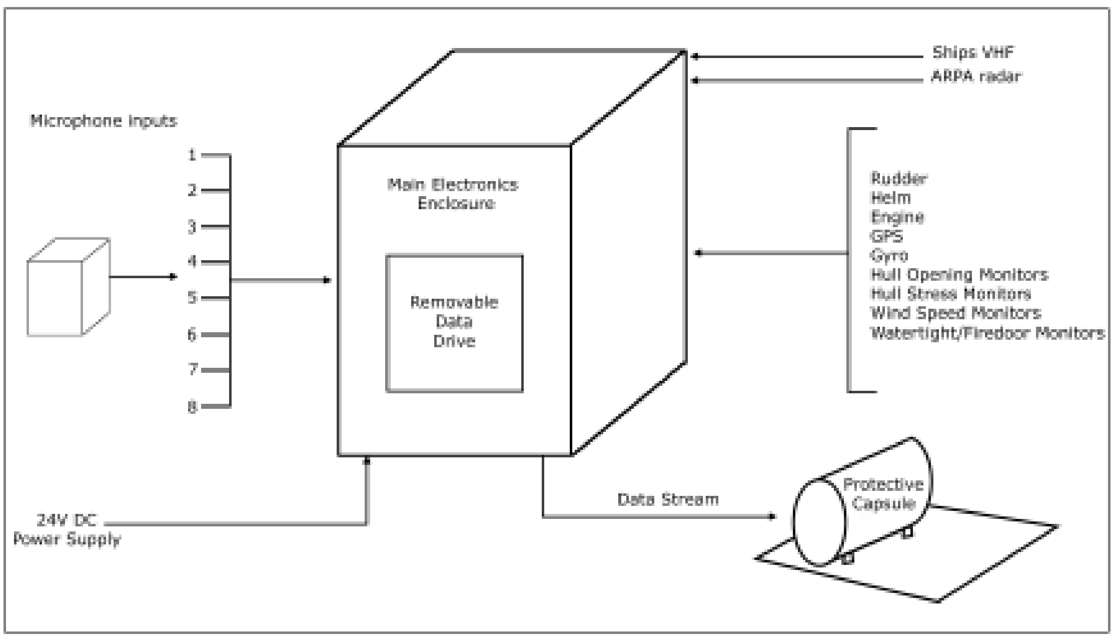

Figure 4. Generic VDR system architecture. Among the parameters recorded on the *Crown Princess* VDR were latitude and longitude, wind speed and direction, rate of turn, heading (magnetic and true), speed (ground and water), rudder (order and position), water depth below keel, engine (command and response), time (hour, minute, second), date (day, month, year), main alarm–hull opening (watertight and fire doors), and radar image. Data were sampled and recorded once per second. The recorded radar video was updated about every 9 seconds.

[32] Two microphones were in adjacent spaces, two on the bridge wings and four on the bridge itself, in addition to the one that recorded the ship's VHF radio.

[33] According to the Safety Board's VDR audio data report: "The majority of the crew conversations were intelligible. The transcript that was developed may indicate passages where conversations were unintelligible or fragmented. This type of recording is usually caused by noise that obscures portions of the voice signals or by a minor electrical or mechanical failure of the VDR system that distorts or obscures the audio information."

Waterway Information

Port Canaveral is located on the Atlantic coast of Florida, approximately 50 miles southeast of Orlando. A dredged entrance channel, 7 nautical miles long and 400 feet wide, runs into the port from the southeast (refer to figure 2). The channel is divided into outer, middle, and inner reaches; cruise ships dock in the inner reach.[34]

The accident occurred in the open ocean about 10 nautical miles east of Port Canaveral, in U.S. territorial waters. According to the navigation chart for the area,[35] water depths near the accident site range from 45 to 62 feet (13.7 to 18.9 meters). The significance of water depth to vessel performance is discussed in the "Shallow Water Effects" section.

Meteorological Information

The National Weather Service marine forecast for Flagler Beach, Florida, to Cape Canaveral, issued at 0353 on July 18, 2006, read: ". . . variable winds 5 to 10 mph. Seas 2 feet. Intracoastal waters smooth. Scattered showers and thunderstorms."

At 1100 on July 18, the National Hurricane Center issued a tropical storm watch for eastern North Carolina. According to the Hurricane Center's bulletin, a tropical depression had formed off the coast about 220 miles south-southeast of Cape Hatteras that "could become a tropical storm later today or tonight." The depression developed into tropical storm Beryl.

Toxicological Testing

Princess Cruises, in accordance with the requirements of 46 CFR 4.06-1(b),[36] directed deck and engineering crewmembers on duty at the time of the accident to provide samples for toxicological analysis. Samples were obtained from the captain, staff captain, relief captain, second officer, fourth officer on watch, relief fourth officer, two helmsmen, and five engineering crewmembers. All samples tested negative for the presence of alcohol and illegal drugs.

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[34] *United States Coast Pilot*, vol. 4, pp. 418-420.

[35] *Ponce de Leon Inlet to Cape Canaveral,* chart 11484, Coast Survey, United States–East Coast, Florida (Washington, DC: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, 1997).

[36] The regulation, which applies to foreign-flag ships operating in U.S. territorial waters, states, in part, "The marine employer shall take all practicable steps to have each individual engaged or employed on board the vessel who is directly involved in the incident chemically tested for [illegal] drug and alcohol use." Samples are tested for the presence of alcohol, marijuana, opiates, amphetamines, cocaine, and phencyclidine.

Crewmember involvement in vessel operations and in the response to the accident precluded testing them for alcohol and drugs immediately afterward. That circumstance is provided for by Coast Guard regulations at 46 CFR 4.06, which require that alcohol tests be conducted within 2 hours of a serious marine incident[37] and that drug tests be conducted within 32 hours "unless precluded by safety concerns directly related to the incident."[38] Alcohol testing is not required more than 8 hours after a serious marine incident.[39]

Officers and crewmembers were breath-tested for the presence of alcohol between 1918 and 1953 on July 18 (4 to 5 hours after the accident). Except for one sample that was collected the morning of July 19, urine samples for drug analysis were collected between 2100 and 2230 the evening of the accident. Thus, all samples were collected within the regulatory time limits.

Survival Factors

Shipboard Response

As required by SOLAS chapter IX, the *Crown Princess* had written emergency response procedures and regulations in place before the accident. They included checklists and contingency plans for 17 different potential shipboard emergencies, among them collision, fire at sea, man overboard, medical emergency, and oil spill.

Princess Cruises fleet regulations instructed that in an emergency, captains were "to maintain an overview of the entire situation" without becoming overly involved in the actual response to the emergency. Captains were to make "such announcements as are necessary to reassure and advise both passengers and ship's company."[40]

Immediately after confirming that the vessel was under control, the *Crown Princess* captain told passengers, over the vessel's public address system, to sit down and stay in place. He explained that there had been a steering failure and that he would give them more information shortly. Subsequent announcements included calls to muster the stretcher party and the passenger-assistance party. The

[37] A serious marine incident is defined at 46 CFR 4.03-2 as (a) a marine casualty or accident that results in any of the following: (1) one or more deaths, (2) injury that requires medical treatment beyond first aid and renders the individual unfit to perform routine duties, (3) property damage exceeding $100,000, (4) actual or constructive total loss of an inspected vessel, or (5) actual or constructive total loss of any uninspected vessel that exceeds 100 gross tons; (b) discharge of 10,000 or more gallons of oil into U.S. waters; or (c) the release of a reportable substance into the environment of the United States.

[38] Title 46 CFR 4.06-3 (a) (1) (i-ii) and (b) (i-ii).

[39] Title 46 CFR 4.06-3 (a) (iii).

[40] Princess Cruises, Fleet Regulations, Fleet Instructions, Emergency Response, EME 1.2, "Emergency Duties—Captain and Senior Officers."

captain also announced to the passengers that they should return to their cabins. He did not sound the general emergency alarm after the incident, which would have signaled passengers to go to their muster stations. As noted earlier, he asked the observers on the bridge wings whether they had seen anyone fall overboard, and they replied that they had not.

Medical facilities on the *Crown Princess* consisted of a primary medical center and a dining hall available for use as a secondary medical facility. The primary medical center was made up of five wards, or rooms, containing seven beds and various basic first aid supplies, as well as a pharmacy, cardiac equipment, and an x-ray machine. Two physicians and three nurses were on the staff. About 16 crewmembers were billeted to the stretcher party, which was divided into four teams.

Both physicians reported that they were in their cabins when the ship began to heel. The senior physician indicated that she suspected that there would be injuries after items in her cabin began falling over. Because the other physician had experienced a similar heeling incident on another Princess Cruises vessel, the *Grand Princess*, 5 months before the accident,[41] he quickly recognized the severity of the event and the potential for injuries. Both physicians went immediately to the medical center. They were joined by passengers with medical training, who provided medical assistance under the supervision of the ship's physicians.

The most seriously injured patients remained inside the vessel's medical center to enable medical personnel to monitor them. Passengers with less serious injuries were asked to wait in the area outside the medical center, and chairs were brought for them. A third area was set up in a dining room for those with minor injuries such as scratches or bruises. Two emergency medical technicians were put in charge of injured passengers in the dining room. The ship's nurses assisted in the medical center and also accompanied stretcher parties to assist injured passengers throughout the vessel. Several passengers with medical training offered to help, and they assisted in the shipboard response.

Shoreside Response

About 1600, the Brevard County, Florida, sheriff's office learned of the accident from the ship's agent. The sheriff's office contacted the fire chief at Canaveral Fire Rescue to advise him of the situation and to inform him of the need to transport between 20 and 50 injured people to hospitals. The fire chief activated the rescue service's mass casualty plan and departed for the cruise terminal.[42] Triage and transport vehicles were in place before the *Crown Princess* arrived.

[41] On February 4, 2006, the *Grand Princess* returned to the port of Galveston, Texas, after a passenger suffered a medical emergency. During the return, the vessel heeled an estimated 12° to 15°, injuring two crewmembers and one passenger. Neither the Coast Guard, the Safety Board, nor the flag state investigated the accident. Princess Cruises attributed the accident to poor communications and poor bridge resource management among the bridge crew.

[42] Canaveral Fire Rescue participates in a mass casualty drill once a year in Melbourne, Florida.

Coast Guard Station Port Canaveral received initial notification of the accident from a passenger on the *Crown Princess* at 1550. Coast Guard personnel in Port Canaveral established direct communication with the vessel, via VHF radio, around 1600. The master reported a steering casualty that caused the vessel to abruptly turn, resulting in injuries to several persons on board. Station Port Canaveral briefed Coast Guard Sector Jacksonville, which contacted Princess Cruises management. Company management informed Sector Jacksonville that the vessel planned to return to port. The Coast Guard Captain of the Port (COTP) later issued a verbal order denying entry to the vessel until a Coast Guard marine inspector could board and verify that the steering gear was functional.

At 1710, a Coast Guard 47-foot patrol boat departed Station Port Canaveral with two Canaveral Fire Rescue officers and two Coast Guard marine inspectors on board to meet the *Crown Princess* while it was returning to Port Canaveral. They boarded the vessel at 1733. The marine inspectors observed a satisfactory basic steering gear test, which was completed at 1743, and conveyed the information to the COTP. About 1800, as the vessel continued its return to port, the COTP rescinded his order, and the vessel was allowed to enter the port. The vessel continued its return to Port Canaveral and lost no time en route as a result of these Coast Guard actions.

After the vessel docked at 1836, helicopters airlifted two seriously injured people to hospitals. Ambulances then transported 101 people—93 passengers and 8 crewmembers—to local hospitals, four in the Cocoa Beach/Melbourne area, one in Orlando, and one in Daytona Beach. A total of 97 fire, rescue, and ambulance department personnel from 10 different agencies, with 9 fire engines, 21 ambulances, and 2 helicopters, responded to the accident, all under the command of the Cape Canaveral Volunteer Fire Department chief, who served as the incident commander.

Tests and Research

Postaccident Steering Tests

On July 20, after the passengers had disembarked and the crew had inspected the vessel and its critical components, the *Crown Princess* departed Port Canaveral for New York. An authorized SAM Electronics technician boarded the vessel at Port Canaveral to test the vessel's NACOS system, with Safety Board investigators, Coast Guard representatives, and a Lloyd's Register surveyor on board to supervise the tests. A representative of Bermuda, the vessel's flag state, joined the group on board.

Before the vessel sailed, the technician performed a comprehensive steering gear test and found that it operated within acceptable limits. During the sailing, the crew activated the NACOS trackpilot, with course changes completed in both heading and course modes. At the captain's direction, the vessel was kept below full speed until it reached the open ocean (July 21). Other vessel conditions during the test were similar to those at the time of the accident, except that no passengers or their baggage were on board and the swimming pools were empty. Data from the vessel's trackpilot showed that the system performed as designed in all test phases. The *Crown Princess* reached New York on July 21.

At the Safety Board's request, SAM Electronics reviewed the short-term voyage recording in the NACOS for evidence of a system malfunction. After the review, company personnel stated, "No malfunction of the Trackpilot could be found in the recording."[43] The company concluded that an improper rudder economy setting[44] and rudder limit setting "can lead to a nonproper function of steering in Heading mode for this ship's speed of 18 to 20 knots together with the measured water depth." The company further concluded, "It must be assumed that the squat effect influenced the steering ability of the ship. The rudder gain setting by the crew for the Trackpilot (Rudder Economy = 5 is a tolerant value) has been too low for [these] conditions." (See "Shallow Water Effects" section for more information.)

Heel Angle Determination

As a result of limitations in the onboard Siemens integrated monitoring, alarm, and control (IMAC) system sensor, only heeling values from starboard 15° to port 15° were measured. The vessel's VDR did not record heeling data, nor was it required to do so. The IMAC retained the heeling data, which were retrieved by Safety Board investigators after the accident.

Because of the likelihood that the vessel's maximum heel angle exceeded the limits of the IMAC data, Safety Board investigators sought other information for determining the maximum angle. Princess Cruises provided the Safety Board with images taken at regular intervals by videocameras positioned at various locations on the ship. One set of images was taken every 2 to 3 seconds by a camera on the vessel's port side. The date and time were stamped on each image.[45] Investigators determined that images recorded during and after the event, from July 18 at 1113:38 through July 19 at 0814:00, were of interest in determining maximum heel angles at specific times during and after the event.

Safety Board investigators digitized part of the video to a computer-based video system so they could review and extract still images. The investigators then

[43] The response from SAM Electronics was dated September 6, 2006.

[44] The rudder economy setting allowed operators to enter one of 10 levels of weather/sea state conditions, with corresponding increases or decreases in rudder movement limits. See "Integrated Navigation Systems" section for details.

[45] The basis of the time stamped on the images is unknown but is consistent with Central European time, offset by 1 hour for daylight saving time.

used two methods to determine the maximum angle of vessel heel from the images taken by the shipboard camera. One method was to measure the angle formed by the apparent horizon in an image and the vertical axis of the vessel, taking into account the distortion created by the camera lens (figure 5).

The other method was to measure the difference between the angle of the shadow created by the vessel on a reference point on the images and the angle that would have been created by the ship's orientation to the sun at that time, given the sun's angle over the horizon and the ship's orientation. Investigators obtained the sun's angle from U.S. Naval Observatory data and the ship's orientation to the sun from VDR data. The maximum angle of heel calculated from the shadow images was 24.2° to starboard at 1524:57 (figure 6).[46]

Figure 5. Image of the *Crown Princess* taken by a ship's videocamera at the maximum angle of heel, with reference lines added by investigators. Stamped time corresponds to 1525:02 eastern daylight time. The apparent bending of the horizon is an artifact of the wide-angle camera lens, which causes straight lines to appear curved and bow outward from the image center.

[46] The ship's VDR clock time was different from the time stamped on the videocamera image. To synchronize the times, investigators assumed that the ship reached its peak heel angle at VDR time 1524:57, halfway between the first and last 15° angles recorded by the vessel's heel sensor.

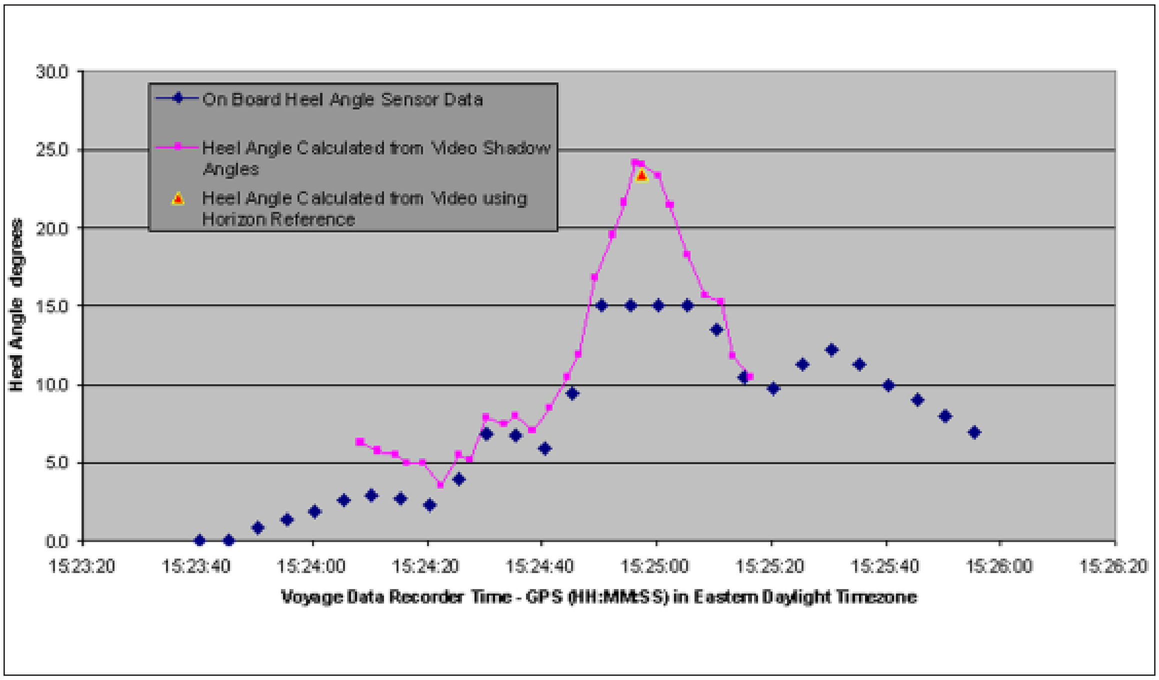

Figure 6. Calculated and recorded heel angles of the *Crown Princess*. The maximum heel angle calculated from shadow images was 24.2°; that calculated from the apparent horizon line was slightly less (23.4° to 23.5°).

Stability Considerations

At the Safety Board's request, the Coast Guard reviewed the stability conditions of the vessel relative to applicable standards of the International Maritime Organization. The Coast Guard found that the ship complied with all International Maritime Organization intact stability[47] requirements for passenger ships at the time of the accident.[48] The Coast Guard's report found that the maximum righting arm[49] occurred around 32°.[50]

[47] Intact stability is a naval architecture term referring to how an intact, or undamaged, vessel responds when heeled over.

[48] *Code on Intact Stability for All Types of Ships Covered by IMO Instruments* (London: International Maritime Organization, 2002), chapter 3.

[49] The concept of the "righting arm" relates to a vessel's ability to restore itself to an upright position. When a vessel heels, both its center of gravity and its center of buoyancy shift to the side, but the center of buoyancy shifts faster. The horizontal difference, known as the righting arm, creates an imbalance that makes the vessel tend to right itself. The righting arm increases as the heel angle increases, but only to a point—the "angle of maximum righting arm." When the heel angle increases beyond that point, the righting arm will decrease. When it reaches zero, the vessel will continue to heel until it capsizes.

[50] Details of the Coast Guard stability review are found in Coast Guard Marine Safety Center Memorandum, Serial H2-0603148, November 24, 2006.

Vessel Dynamics

Safety Board investigators studied the vessel dynamics both before and after the second officer took manual control of the steering. The investigators used VDR data from about 5 seconds before the trackpilot was disengaged until about 15 seconds after the commanded rudder oscillations ceased. Figure 7 plots the second officer's wheel (rudder) commands against the rudder response and the heeling angle.

The data show that after the second officer disengaged the trackpilot at 1524:05, the vessel's rudder positions corresponded to the rudder commands for about 10 seconds. Then, at 1524:15, the rudder positions began to deviate from the wheel input as the rudders lagged the wheel commands.[51] The deviation lasted until shortly after the rudders were commanded to midships (1525), after which the vessel gradually returned to even keel. The vessel's response lagged both the rudder commands and the rudder positions. From 1524:30 to 1525:10, while the rudders remained at port, the vessel's heading diverged from its direction of motion. That difference is known as the drift angle. The greater the drift angle and the greater the speed, the greater the resultant heel angle. The vessel's maximum heel occurred about 1524:57, as shown by the red line in figure 7.

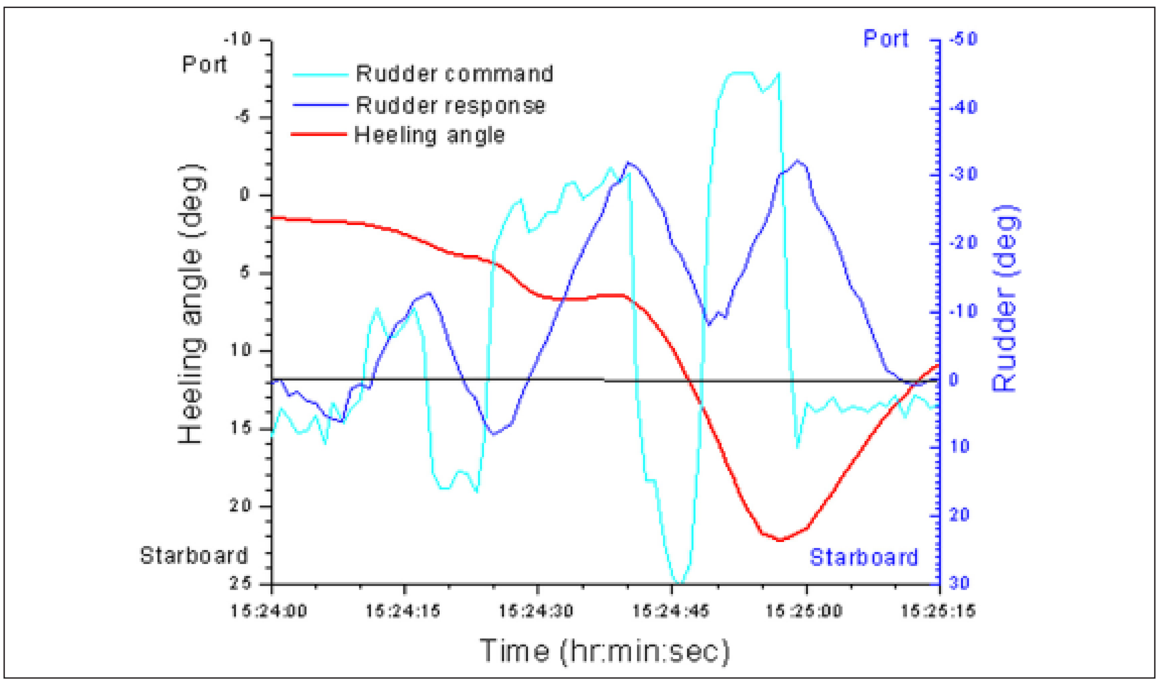

Figure 7. After the second officer began steering the vessel manually, he turned the wheel faster than the rudders could follow, as shown by the divergence between the rudder commands (light blue line) and the rudder responses (dark blue line). As the vessel attempted to respond to the commands, it heeled increasingly to starboard (red line).

51 Lag results when the rate of wheel inputs exceeds the rudder response rate, which for the *Crown Princess* was 3° per second.

Shallow Water Effects

As shown in figure 8, the water depth was about 5 meters (about 16 feet) below the keel of the *Crown Princess* during the first part of the trip, gradually increasing to 8.3 meters (27.2 feet) at 1524, when the second officer assumed the conn, and reaching 10.7 meters (35.1 feet) at the end of the accident sequence.

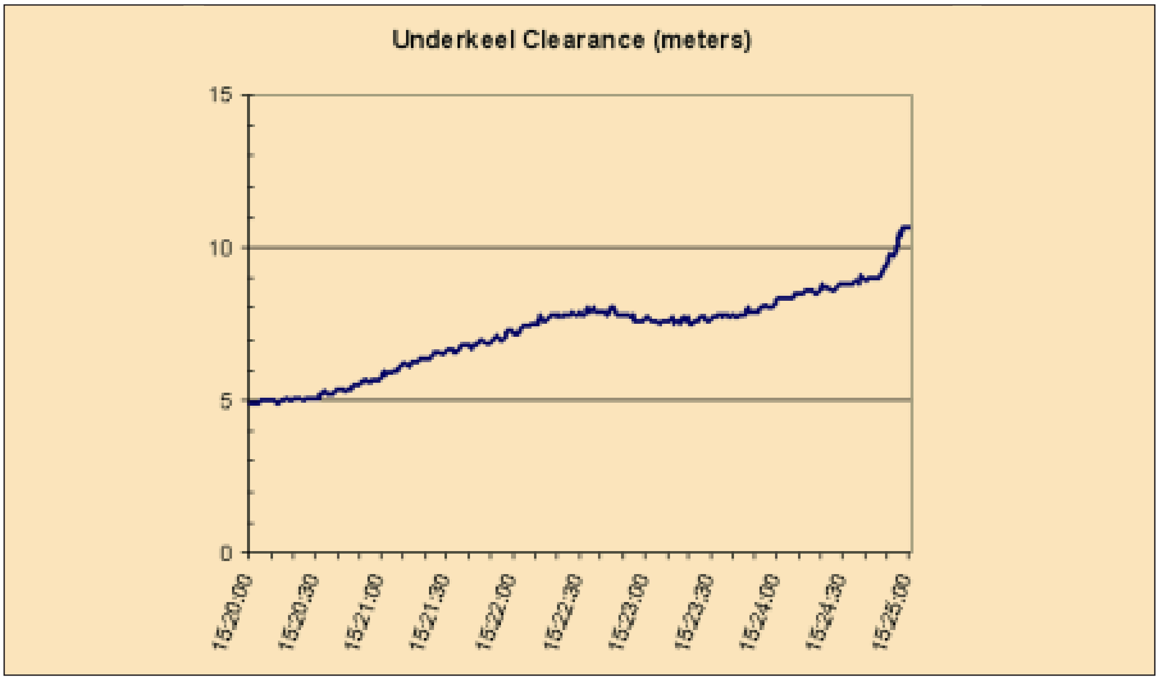

Figure 8. Underkeel clearance of the *Crown Princess* during the accident sequence, from data recorded by the vessel's VDR.

When a vessel moves through shallow water, it experiences a complex hydrodynamic phenomenon that affects both its clearance above the waterway floor, known as squat, and its steering precision. As a vessel's speed increases, the water level around the hull is lowered, because as water moves under the hull, the velocity and kinetic energy of the water increase. To compensate for the increase in kinetic energy, the potential energy (energy of a system derived from elevation rather than motion) must reduce, because the total energy of a system must remain constant. The reduction in potential energy is achieved through the lowering of the water level around the hull. Squat is approximately proportional to the ship's speed squared; hence, halving the speed reduces the squat effect by a factor of four.[52]

52 Navigation and Vessel Inspection Circular No. 2-97, change 1, COMDTPUB P16700.4; Ch-1 <http://www.uscg.mil/hq/g-m/nvic/2 97/n2-97ch1.htm> (accessed May 3, 2007).

The greater a vessel's speed in shallow water, the less predictable its steering.[53] That holds true whether the vessel is steered automatically or manually. Test trials performed on model ships in tanks show that turning radius increases exponentially with a reduction in water depth under the keel. Some trials show that a ship's turning diameter increases 60 to 100 percent at a water depth of 1.25 times ship's draft.[54] A ship's draft of 8.5 meters (27.9 feet) and an underkeel clearance of 8 meters (26.3 feet) equals a water depth of 16.5 meters (54.1 feet), giving a ratio of water depth to ship's draft of about 2:1 and meeting the general definition of shallow water.[55]

Princess Cruises informed its crewmembers about squat effects in its fleet regulations and deck standing orders:[56]

> …The effects of squat can have an adverse affect on the ship's handling characteristics, and these must be borne in mind when in confined waters:
>
> - The vessel's stopping distance and turning circle is increased.
> - The propellers and rudder become less effective.

The company also posted information about squat effects on the bridge of the *Crown Princess* (table 4).

Table 4. Information about squat effects posted on the *Crown Princess* bridge.

Draft Increase (Loaded)		
Underkeel Clearance	Ship's Speed (knots)	Estimated Maximum Squat (meters)
4 meters	24	3.48
	14	1.18
	4	0.01
8 meters	24	3.0
	4	0.08

NOTE: The notice posted on the bridge also included other information.

[53] A. J. Jurgens. and A. D. Jager, "Controllability at Too High Speeds in Too Shallow Water," *Proceedings of MARSIM 2006* (International Conference on Marine Simulation and Ship Manoeuvrability), Terschelling, The Netherlands, 2006.

[54] Edward V. Lewis (ed.), *Principles of Naval Architecture,* vol. 3, *Motions in Waves and Controllability* (Jersey City, New Jersey: Society of Naval Architects and Marine Engineers, 1989), pp. 280-281.

[55] Princess Cruises defined shallow water as "depths less than twice [vessel] draught" (NAV.7, Fleet Regulations and Standing Orders). Other sources define shallow water as either two or three times ship's draft. *Principles of Naval Architecture* (vol. 3, p. 279) defines shallow water as a water-depth-to-ship's-draft ratio of 3 or less.

[56] Princess Cruises, Fleet Regulations, Deck Standing Orders, Navigation, NAV 7.10, "Squat."

After the *Crown Princess* accident, SAM Electronics commissioned a university to determine the effect of shallow water and high vessel speed on the maneuvering characteristics of a large vessel. The study found that in water depths of about 6.8 meters (22.3 feet) below the keel, the yaw-checking ability of a vessel the size of the *Crown Princess* will be "significantly reduced," and the INS's ability to control the vessel steering will be reduced as well. The author concluded:[57]

> . . . Our analysis could show that due to the large beam of the vessel, a steady heel results in a large alteration of the hydrodynamic blockage which then results in a large impact on squat as such. A secondary yawing moment is generated due to the steady heel which forces the vessel into a turning circle exactly to the side of the heel. If the heel is initiated by an initial turning motion, then the secondary heeling moment will clearly amplify this turning motion, which can then only be compensated by more rudder action.
>
> . . . As the rudder action required to yaw check the first turning must result in a large rudder moment, all this results in a hunting where the amplitude of that hunting gradually increases. . . . According to our analysis, the only way to control the hunting is to keep the yawing instability of the ship under a certain limit, which must also reduce the squat effect. . . .
>
> As the auto pilot sees a completely different system compared to its deep water design characteristics, there is according to our results no possibility for the autopilot to cope with such kind of situation.

After receiving information from its customers and the university study, SAM Electronics made several changes to its NACOS equipment (the updates are available as an option to vessel owners and only on generation 5 NACOS) as well as to its training material and operating manual:

- The NACOS autopilot will operate normally until the ratio of water depth to ship's speed reaches a theoretical threshold at which shallow water effects become apparent (based on the formula $d < 0.085v^2$, where d = depth in meters, v = speed in knots). At that point, the operator hears a warning sound. If the water-depth-to-speed ratio goes lower (based on the formula $d < 0.065v^2$), a second alarm alerts the operator that the ship has entered the critical squat range, below which limit, according to the university study, the ship's maneuverability changes significantly.[58] The alarm points are set based on vessel-specific information. Both alarms

[57] S. Kruger, "Determination of the Squat Effect on the Course-Keeping Ability of a Large Cruise Liner" (Hamburg: *Technische Universität Hamburg-Harburg, Institut für Entwerfen von Schiffen und Schiffssicherheit*, 2007), p. 3.

[58] The coefficients 0.085 and 0.065 are based on theoretical computations. For the value 0.085, the university study stated that it is well known that shallow water influence can be found if the wavelength of the ship's own wave system is greater than two times the water depth. This results in a relation between water depth (d) and ship's speed (v) of $d = 0.085v^2$, when ship's speed is in knots. The value 0.065 comes from theoretical computations for a hull form equivalent to that of the *Crown Princess*. The influence of shallow water was found to be significant for depths equal to or below $0.065v^2$.

can be activated and deactivated independently. They are activated only if the trackpilot is engaged and the limit values persist for a defined period.

- A "low rudder limit" alarm sounds if the rudder limit is set so low that the next turn in track mode cannot be executed with the preplanned turn radius. In addition, a "high rudder limit" alarm operates using a new parameter called "maximum allowed rate of turn," which is used to calculate an upper limit for the rudder limit set by the operator. Its value is determined by the ship's turning ability and its speed.

- Information on shallow water and high-speed effects (such as squat) on vessel maneuverability was added to the NACOS training curriculum and the NACOS operating instructions. The following warning about the squat effect was added to the operating instructions:[59]

> Shallow water may effect [sic] the dynamics and manoeuvrability of a vessel. Shallow water is considered to be a depth of less than 2.5 times the draught of the vessel. If sailing with high speed in shallow water the draught of the ship may increase considerably caused by the squat effect. The squat effect increases with higher speed and lower water depth.
>
> These effects may change the designated steering behavior of the ship in a material manner. Previously set parameters for the TRACKPILOT ability to steer the ship will no longer match with that ship behavior.

After the accident, as noted earlier, an authorized SAM Electronics technician tested the vessel's NACOS INS. He also prepared a one-page guidance document on the trackpilot for Princess Cruises bridge crews. The document listed the trackpilot parameters and summarized the control given by the various rudder economy settings, as well as the weather conditions under which they should be used. The rudder limit definition from the operating manual was also reproduced, with the following comments and recommendations:

> The rudder limit setting is a parameter that must be manually adjusted depending on the vessel's speed and sea conditions. At high sea speeds a small rudder angle should be entered, i.e. 5 degrees. At slower speeds, when more rudder angle is required to perform a turn (required rate of turn not attainable with the smaller limit) a larger rudder limit should be utilized, i.e. 15 degrees.
>
> Acknowledgment of the [rudder limit] alarm silences the buzzer only, but continues the rudder limitation.

59 SAM Electronics, *Operating Instructions*, section 36.1.

Operational and Management Information

Corporate Organization

Princess Cruises, founded in 1965, became a subsidiary of the Carnival Corporation in 2003.[60] In fall 2004, after acquiring Cunard Cruise Lines, Carnival Corporation merged the fleet operations of Cunard Lines and P&O Cruises of Australia with those of Princess Cruises.[61] At the time of the accident, Princess Cruises, Cunard, and P&O Cruises operated under a single management structure, while retaining separate brand identities. Princess Cruises considered deck officers to be interchangeable on the vessels of the three companies.

Crewmembers on Princess Cruises, Cunard, and P&O ultimately reported to the vessel captains, while the captains reported to the Princess Cruises fleet captain, marine operations. The fleet captain and senior vice president, fleet operations, reported to the executive vice president, fleet operations. The executive vice president reported to the chief executive officer of Princess Cruises. The chief executive officer of the three cruise lines was a director of Carnival Corporation & PLC and reported to the vice chairman and chairman of the board of the corporation.

Personnel at both Princess Cruises and Holland America Line, another Carnival Corporation subsidiary, indicated that the corporation allowed the individual cruise line subsidiaries latitude in overseeing vessel operations. That latitude extended to personnel selection, training, safety management systems, and vessel design and acquisition.

Princess Cruises Operations

Fleet Oversight. Princess Cruises management personnel told Safety Board investigators that they had known the fleet captains for many years and were familiar with both their strengths and their weaknesses. Management personnel regularly visited the vessels to observe vessel operations. All ship's officers met with their superiors at the midpoints and ends of their assignments to review and discuss their performance. The performance appraisals were then sent to the senior vice president, marine operations, and finally to the fleet captain.

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[60] See Princess Cruises website <www.princess.com/news/article.jsp?newsArticleId+na735&submit =pk> (accessed December 10, 2007).

[61] The corporate website states: "Carnival Corporation & plc is a global cruise company and one of the largest vacation companies in the world. Our portfolio of leading cruise brands includes Carnival Cruise Lines, Holland America Line, Princess Cruises and Seabourn Cruise Line in North America; P&O Cruises, Cunard Line and Ocean Village in the United Kingdom; AIDA in Germany; Costa Cruises in southern Europe; and P&O Cruises in Australia" <http://phx.corporate-ir.net/phoenix.zhtml?c=200767&p=irol-prlanding> (accessed October 10, 2007).

The fleet captain, marine operations, oversaw a staff of two marine inspectors who visited each vessel at least once a year to observe operations and ensure compliance with procedures. The inspectors operated independently of the auditors that the company dispatched as part of its required internal safety management system audits. The inspectors reported their findings to the vessel captains, with suggestions for improvement, if necessary, as well as to Princess Cruises management. The company began the program because the demands of overseeing its growing fleet prevented senior management from visiting the vessels as often as they would have liked.

Princess Cruises also read out VDR data and listened to VDR conversations after all incidents of concern to the company. Management personnel estimated that in the 3-year period before the accident, they had read out and listened to about 12 VDRs.

Watchkeeping Policies and Procedures. Princess Cruises watchkeepers had the discretion to steer using an automated INS mode or manually, within the standards that the vessel captains established in their standing orders. Deck standing order NAV.7.14 of the company's fleet regulations[62] advised crewmembers to use the INS because "it ensures [that the] maximum information is available to officers." However, it advised crewmembers not to rely exclusively on the INS for navigation information but to verify the information against chart and other navigational information. As the order stated, "The Integrated Bridge System is not a substitute for maintaining a safe navigational watch."[63]

Standing order NAV.7.14 attached the following provisos to the selection of the trackpilot's operational mode:

> *Operation in Heading Mode* should be selected when a steady heading is required, particularly when in close proximity to other vessels. If a close-quarters situation is developing, then Heading Mode should be selected in preference to Course or Track Mode.
>
> *Operation in Course Mode* may be appropriate when necessary to deviate from the System Track when a set CMG ["course made good," that is, course over the ground] is desirable.
>
> *Operation in Track Mode* may be used provided the System Track and/or Electronic Chart positioning has been confirmed as reliable and traffic conditions permit. Particular attention shall be paid to Position and Speed Sensor status, as well as the Horizontal Chart Datum in use prior to selection.

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[62] Princess Cruises, Fleet Regulations, Deck Standing Orders, Navigation NAV.7.14, "Integrated Bridge Systems (IBS)," reissued May 2002.

[63] Princess Cruises referred to its INS as an integrated bridge system (IBS). Until recently, the terms IBS and INS were used interchangeably. However, International Maritime Organization regulations now distinguish between them. An INS is considered to be a component of an IBS, which includes other components such as communications, security, and cargo control.

The standing order directed second officers and deck officers of higher rank on ships having integrated bridge systems to complete "an appropriate training course" before being permitted sole charge of the watch while at sea. In addition, Princess Cruises advised its watchkeeping officers to "be familiar with [the system's] alarm messages, their meaning, and the action to take on their activation."

Postaccident Actions. Within days of the *Crown Princess* accident, Princess Cruises issued a letter to its deck officers instructing them not to use the NACOS trackpilot or speed pilot systems on their ships until they were satisfied that all watchkeeping officers fully understood the "correct and safe operation" of the equipment. Watchkeeping officers were also instructed to reread the NACOS instruction literature. Over the next several months, additional instructions were issued regarding the use of checklists for transferring the conn, for assuring deck officers' familiarity with bridge procedures and emergency equipment, and for engaging or disengaging automated steering. The cruise line also cautioned officers about the effects of shallow water on steering, reminding them to be especially careful about using the trackpilot in shallow water "at higher speeds." In a fleet regulation reissued in May 2007,[64] captains were informed that ". . . good seamanship would require that following a departure from a port anchorage either they or their designee (staff captain) should remain on the Bridge until satisfied that the ship and the Bridge Watch are settled."

The cruise line informed the Safety Board that it had increased the complement of its bridge crew by adding a third officer. In addition, the company said that it was undertaking a trial period on nine of its vessels in which the first officers would divide the 0400-to-0800 and 1600-to-2000 watches, to create increased flexibility in the oversight by first officers of new officers during "demanding times on their watches."

In a fleet regulation reissued in September 2007,[65] Princess Cruises required the reporting of marine casualties "wherever they occur" to the flag state. The regulation stated: ". . . if the casualty occurs outside U.S. territorial waters but the ship is bound directly to a U.S. port, then a report must be made to the [Coast Guard]." In a related regulation,[66] the cruise line required the immediate notification of its corporate offices if any on a list of 13 incidents occurred, to include "any incident causing the vessel to heel more than 5 degrees."

Princess Cruises managers told the Safety Board that after the accident, they established a professional marine standards department to enhance the standards, protocols, and procedures of their operations, and to develop a program of human

[64] Princess Cruises, Fleet Regulations, Deck Standing Orders, Bridge Procedures BRP.3.1, "Company Navigation Orders," reissued May 2007.

[65] Princess Cruises, Fleet Regulations, Fleet Instructions, Legal and Documentation LEG.7.2, "Marine Casualties," reissued September 2007.

[66] Princess Cruises, Fleet Regulations, Fleet Instructions, Communications COM.2.2, "Incident Reporting to Shore Management," reissued September 2007.

element understanding. No additional information was provided regarding the composition of the department, its location in the Princess Cruises management hierarchy, or the manner in which the department would carry out its duties.

Princess Cruises also sent its SAM Electronics–certified NACOS trainer to its vessels to conduct 3-hour on-site training sessions in the use of the NACOS INS. The training was intended to serve as both refresher training for those who had previously completed a NACOS course and initial training for those who had not. In addition, the cruise line informed the Safety Board that it had employed an inhouse bridge team equipment trainer, approved by SAM Electronics to conduct NACOS training. The individual was to give bridge personnel one-to-one instruction on their NACOS equipment during 3-day visits to their vessels. Princess Cruises also required all captains to attend a 5-day bridge resource management course, irrespective of the year in which they had first completed such training. Princess Cruises managers indicated that they were revising a course for deck officers that would include practicing emergency scenarios in a full 360° bridge simulator, using a variety of scenarios.

Princess Cruises also implemented the use of a new technological aid for accounting for passengers after a mishap, in addition to developing new procedures for responding to mishaps both on vessels and at its corporate offices and for reporting mass casualty incidents to authorities. The cruise line indicated that it recommended that user-friendly guidance from operations manuals specific to vessel bridge equipment be developed and placed in a readily accessible location on vessel bridges.

Additional Information

Heeling Incidents on Cruise Vessels

Previous Occurrences. As part of the investigation of the *Crown Princess* accident, Safety Board investigators interviewed representatives of other cruise lines based in the United States[67] regarding heeling incidents on their vessels in the 15 years before the accident. To focus on more severe episodes, investigators defined a heeling incident as an unexpected and unplanned heeling of a vessel during a turn, reaching an angle equal to or greater than 6°. Cruise lines that provided heeling incident data to the Safety Board maintained different record-keeping systems with varying definitions of heeling incidents and accidents, and employed different investigation procedures.

[67] Norwegian Cruise Lines, Holland America Line, and Royal Caribbean/Celebrity cooperated with the Safety Board's investigation, in addition to Princess Cruises, which, at the Safety Board's request, voluntarily submitted internal information on heeling incidents and accidents that had not been investigated by government agencies.

Most of the incidents were not required to be reported to a government agency because of their location or the scope of the event, and therefore most were not investigated by such agencies. The cruise lines themselves supplied most of the data on incidents. Because the intent of the Safety Board's review was to determine whether commonalities were present among operator errors in the use of INSs, incidents not involving INS use, such as collision-avoidance maneuvers, were not considered.

Safety Board investigators reviewed information on 13 accidents and incidents involving large passenger cruise vessels (those carrying more than 1,000 passengers) equipped with an INS. Five cases were found in which the incident arose exclusively from a technical malfunction in either the vessel's steering system or its INS.

In a 1994 incident, a vessel turned sharply to port after the second officer shifted vessel steering control from heading mode to track mode in the vessel's INS. The cruise line investigated the incident, which occurred outside U.S. territorial waters. The bridge officer on watch was unaware of a requirement that, before making the shift between the two modes, the ship had to be within 5° of the proposed course heading. The proposed track heading diverged 24° from the proposed heading, and with the rudder limit having been increased from 5° to 10°, the vessel turned sharply to the proposed heading. Thirteen passengers and crew received minor injuries in the incident. The cruise line determined that the operating manual did not provide guidance on this type of situation, and that it had no policy to train deck officers in using the INS. It later revised its own INS operating procedures and training standards to address those issues.

In a 1999 incident, a passenger vessel turned sharply to starboard when a watchkeeper engaged the INS after manually steering the vessel. The cruise line, which investigated the incident, determined that the watchkeeper had entered an incorrect rudder limit, one that was considerably beyond the maximum rudder limit that the vessel permitted. However, the INS accepted it and then attempted to turn the vessel sharply. Further examination revealed a fault in the system that was subsequently corrected.

In 2001, a passenger vessel turned sharply and heeled, injuring 28 passengers and crew. The Coast Guard, which investigated the incident, found that a watchkeeper had entered a heading into the INS that was 180° different from the desired course. The vessel turned sharply to the "new" course. The Coast Guard initially restricted the vessel's use of the INS until the reason for the failure could be determined. Subsequent investigation found no fault in the system and no reason for the erroneous entry. The cruise line revised its INS policies, reducing the maximum allowable rudder limit from 20° to 5°. In addition, the Coast Guard and the International Council of Cruise Lines (ICCL) prepared and distributed a safety alert on the importance of securing equipment for rough seas, and on the need to develop policies and training programs to ensure the proper use of autopilot systems.

Seven months later, a different vessel of the same cruise line heeled to an estimated 6° to 7°, slightly injuring one passenger. The Coast Guard, which did not investigate the incident, worked with the cruise line to obtain and examine data from the event. Coast Guard correspondence indicates that it was satisfied that the changes regarding training and INS use that the cruise line had implemented in response to the heeling event 6 months earlier had addressed the deficiencies identified in both events.

In 2005, a cruise vessel with a pilot on the bridge turned sharply after the helmsman implemented a pilot-requested course change through the INS, and the vessel turned beyond the selected heading. The vessel heeled to 6°, but no one on board was injured. The cruise line, which investigated the incident, attributed it to the deck officer's incorrect method of entering the new course into the vessel's INS, which allowed the autopilot to exceed the set rate of turn.

Monitoring and Reporting. There is no Coast Guard or International Maritime Organization requirement for cruise lines to report heeling incidents that do not meet accident-reporting criteria to either INS manufacturers or government agencies, although steering and propulsion failures must be reported.

Sperry Marine and SAM Electronics representatives told investigators that they learned about INS-related heeling incidents from the news media, local technical representatives, or directly from their customers. Both companies indicated that, when informed of a heeling incident or accident, their primary concern was to identify system malfunctions rather than operator errors. Sperry Marine indicated that the only formal investigation it conducted of an accident involving a vessel supplied with its system was the one involving the *Exxon Valdez*.[68]

SAM Electronics's response to an incident or accident was dictated by a formal mechanism it had developed and implemented. The vessel, type of equipment on board, and the nature of the involvement of its product in the perceived cause of the incident determined the company's response. If it was determined that its product was not causal to the incident, no further action was taken, other than reporting the information to its corporate parent. If it was determined that its product played a role in the cause of the incident, SAM Electronics would designate an individual to direct internal and external activities in response. SAM Electronics personnel were also assigned to analyze the data and propose product modifications, as needed.

SAM Electronics maintained a record of steering-related incidents and accidents involving vessels equipped with NACOS equipment. Its record contained 12 incidents and accidents, from 1995 to the *Crown Princess* accident. One incident involved a 1995 grounding, one a 1996 incident of uncertain type, and one a heeling incident that resulted from an avoidance maneuver. Two involved cargo vessels

[68] National Transportation Safety Board, *Grounding of U.S. Tankship* Exxon Valdez *on Bligh Reef, Prince William Sound Near Valdez, Alaska, March 24, 1989*, Marine Accident Report NTSB/MAR-90/04 (Washington, DC: NTSB, 1990).

that experienced faults in NACOS components, and one involved a 2004 incident of uncertain type.

The Safety Board obtained information on 13 steering-related incidents, as well as a list of 23 minor incidents provided by a cruise line. Nine of the incidents in the Board's records were on SAM Electronics's list.

Integrated Navigation Systems

Design. INS equipment is approved by government test and approval agencies on the basis of the standards and guidelines established by the International Maritime Organization and the performance and testing standards set forth by the International Electrotechnical Commission.[69] Manufacturers design the systems to conform to classification society standards,[70] requirements of the International Maritime Organization and International Electrotechnical Commission, and the standards and requirements of the flag state holding the vessel's registration. Bermuda, the flag state of the *Crown Princess*, accepted the NACOS type-approval of the German government agency.[71]

According to Sperry Marine personnel, at the time of the accident, about 80 percent of cruise vessels were supplied with a NACOS INS, about 10 percent with a Sperry INS, and about 10 percent with equipment supplied by four other manufacturers. Princess Cruises vessels, like most large passenger vessels, were equipped with NACOS INS equipment.

Early 1980s versions of the NACOS contained radar information with ARPA, display of navigation information, and automatic warning and alarms. Subsequent generations introduced predicted path displays, electronic charting (referred to as chartpilot), chartradar and multipilot, with VDR and automatic identification system (AIS).[72]

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[69] Regulations and guidelines pertaining to the NACOS at the time of the accident are discussed in appendix D.

[70] Classification societies are private, independent organizations that establish and apply technical standards for the design, construction, and survey (inspection) of ships. Many countries delegate responsibility for some regulatory functions to classification societies, such as inspection for compliance with certain national and international regulations and issuance of some safety certificates, and may also adopt class society rules as their own national standards.

[71] The International Electrotechnical Commission had not established INS test standards when the NACOS was installed on the Crown Princess. The German approval agency BSH (*Bundesamt für Seeschifffahrt und Hydrographie*) type-approved the NACOS as a track control and heading control system. Approval of the trackpilot system was according to International Electrotechnical Commission standard 62065, "Track Control Systems–Operational Performance Requirements, Methods of Testing and Required Test Results," based in turn on International Maritime Organization Maritime Safety Committee resolution MSC.74(69), Annex 2, "Recommendations on Performance Standards for Track Control Systems." Approval of the heading control system was according to Maritime Safety Committee resolution MSC A.342(IX), "Recommendation on Performance Standards for Heading Control Systems," as well as International Organization for Standardization (ISO) standard 11674, "Ships and Marine Technology—Heading Control Systems."

[72] AIS is a shipboard broadcast system that provides identifying information on other vessels within 8 to 10 nautical miles of a ship, with such additional information as location, heading, speed, and rate of turn.

NACOS generation 5 was introduced in 2005. (As noted earlier, the *Crown Princess* was equipped with model 65-5.) Generation 5 featured changes in the trackpilot that conformed to mandatory changes required by the International Maritime Organization. In addition, the latest version featured a fully integrated VDR that captured radar data.[73] The NACOS model on the *Crown Princess* contained the following components: radarpilot, chartpilot, multipilot, conning pilot, and trackpilot.

The radarpilot displayed radar information about the environment around the vessel as seen by the radar system. The trackpilot could be controlled and monitored from the radarpilot workstation, thus enhancing the vessel's basic autopilot function with information on nearby vessels.

The chartpilot combined nautical information, route planning, and geographical information with digital charts. It provided route-monitoring information including position, gyroscope heading, rate of turn, speed, course, date, time, distance to next way point or object, time to next way point or object, wind direction and velocity, engine power, propeller pitch, shaft revolutions per minute, rudder position, and thruster position, if available.

The multipilot combined ECDIS with radar information to display planned and actual position, with location of nearby vessels, on an electronic chart. Among the information provided to the officer having the conn were heading, rate of turn, course, drift angle, extent off course, extent off track, estimated time of arrival to next way point or position, time to travel to next way point or position, water depth, wind velocity and direction, and engine and rudder information.

Steering through the trackpilot could be set to one of three modes: *heading mode*, a mode comparable to a conventional autopilot in which the gyrocompass would determine the vessel heading; *course mode*, in which the true course would be maintained with compensation for drift and wind; and *track mode,* which would steer the vessel along a predetermined track using either specific navigation points entered by the operator or navigation points along a predetermined route, with compensation for drift and wind. Track mode steering could be fully automated, requiring crewmember confirmation only in the case of a course alteration.

Trackpilot provided all the information included in the previous components with such additional information as GPS position, rudder economy setting, rudder limit, selected limit on course, distance from track (or drift), rhumb line (line of constant bearing) to track, time to next way point, course correction, and information on the track itself.

Among the trackpilot parameters that could be selected at the option of the watchstanders were rudder economy, rudder limit, and course limit. The rudder economy setting allowed operators to enter one of 10 levels of weather/sea

[73] The International Maritime Organization did not require VDR integration, an optional item in NACOS generation 5.

state conditions, with resulting rudder movement limits increased or decreased, according to the setting. Level 1 was for calm seas and wind conditions, while levels over 6 were to be used when conditions were "very bad" (terms in quotes indicate terms from the NACOS operating manual). Level 5, the rudder economy setting that had been set into the vessel's trackpilot at the time of the accident, was to be used when conditions were "bad." With increases in rudder economy setting, designed to be used for increasingly rough seas, vessel heading was allowed to fluctuate increasingly. The NACOS manual described steering in level 1 as "precise" and, as the levels increased, steering became increasingly "tolerant."

Operators were expected to apply higher rudder movement restrictions during rough seas by inputting higher rudder economy settings. The NACOS operating manual stated:[74]

> Economically advantageous optimisation between track-keeping and frequency of changing of the rudder angle, depending on sea state and wind, is achieved by means of the "rudder economy" parameter. This is comparable to a combination of the control variables "rudder," "counter rudder" and "yaw" of a conventional autopilot. A common feature of the following [rudder] limits is that, when the set value is reached or exceeded, a corresponding alarm appears. The rudder angle setting which the trackpilot specifies as the maximum value for the rudder control system can be set under **Limits** in the **Rudder** Field. The rudder limit value should be reduced if a constant course is to be steered for a long time on the open sea or if, for example because of the loading state or for other reasons, large angles of the rudder are not permitted. When the rudder limit value is reached, the **TP** [trackpilot] **Rudder Limit** alarm appears [*emphasis in original*].

At higher vessel speeds, SAM Electronics recommended setting the rudder limit lower than at lower speeds to prevent excessive rates of turn and vessel heeling. The trackpilot manual specified: "The rudder limit value should be reduced if a constant course is to be steered for a long time on the open sea or large rudder angles are not permitted."

The INS recorded INS data independently of the VDR, which recorded data mandated by the International Maritime Organization.[75] On the *Crown Princess*, INS data were registered on both a short-term and a long-term recording, stored in the chartpilot unit and capable of being replayed by specialized hardware and software (the chartpilot electronics unit). In addition, the system recorded errors in a log file that was stored on the multipilot radar unit.

Training. Neither the International Maritime Organization, Bermuda (the state of registry of the *Crown Princess*), nor the Coast Guard required mariners to be trained in INS use. Ship owners or operators decided on the type of training, if

[74] SAM Electronics, *Operating Instructions*, pp. 207-208.

[75] No international requirements address VDR storage of inputs to vessel INS units. See "Voyage Data Recorder" section.

any, to be provided. INS manufacturers were required only to provide customers with user manuals and system documentation.

The International Maritime Organization developed an IBS/INS "model course" that presents a curriculum on system use (appendix E). Member nations are not required to adopt the model curriculum or to certify IBS/INS courses. There is no International Maritime Organization requirement that students completing IBS/INS courses demonstrate proficiency in using the systems, or that a maximum period be permitted to elapse before someone who has completed an IBS/INS course can work with a shipboard IBS/INS while serving as a watch officer. In addition to developing the model course, the International Maritime Organization's subcommittee on Standards on Training and Watchkeeping (STW), at its session in 2006, considered the need for a comprehensive review of the International Convention on Standards of Training, Certification, and Watchkeeping for Seafarers (STCW) and the STCW code, and proposed a work item with a target completion date of 2008.[76]

At the 2007 meeting of the International Maritime Organization's Maritime Safety Committee, revised performance standards for INS and guidelines on the application of SOLAS regulation V/15 related to INS, IBS, and bridge design were adopted.[77] Included was guidance to equipment manufacturers for familiarizing mariners with INS use on board vessels (appendix F).

Representatives of Sperry Marine told investigators that the company conducted a 40-hour class in the use of its ECDIS at its Charlottesville, Virginia, facility. A typical class consisted of 30 hours on a multiconsole INS installation that mimicked a typical ship's bridge and about 10 hours on an ECDIS simulator. Within the 40-hour time frame, instructors generally tried to match class time with demonstrated student progress. Crewmembers were taught the relationship between sea state, rudder movement, and rudder hunting. That is, during rough seas, the Sperry system would limit rudder movement, and as a result vessel yaw fluctuations would become limited around a given heading. A crewmember could also select a particular sea state that would have the same effect on rudder movement.

SAM Electronics conducted training in the NACOS system at its Bremen, Germany, training facility. Customers could order the training and take it in Bremen or at another site they selected. Carnival Corporation conducted NACOS training, using a SAM Electronics–certified instructor, at its training center in Southampton, England. Regular training began about March 2006. Classes could cover vessel-specific NACOS designs, but because a typical class contained students from different vessels, the classes usually dealt with generic systems.

[76] The STCW code sets minimum international training standards for professional mariners. It was last amended in 1995.

[77] Report of the International Maritime Organization Maritime Safety Committee, 83rd session, October 2007. The performance standards for INS are found in resolution MSC.252(83), and the guidance to SOLAS regulation V/5 is found in SN.1/Circ.265.

The standard SAM Electronics NACOS training was conducted in a 4-day class. The first day included an overview of the company, the purpose of an INS, and a history of the NACOS. The design and system architecture of the current NACOS were outlined. The second day covered the operation of major NACOS components, including radar, ARPA, and ECDIS. The third day focused on the operation of the multipilot and trackpilot, including trackpilot modes, trackpilot accuracy and limitations, and track and speed control. On the last day, students completed exercises in voyage planning, execution, and monitoring using NACOS. The course material was then reviewed and new system elements discussed. If time allowed, students were presented with a system failure and asked to respond effectively. Exercises were conducted on computer-based simulators that displayed NACOS information matching actual vessel displays.

SAM Electronics representatives told investigators that because the company considered the effects of shallow water and high vessel speed on vessel steering to be part of the basic knowledge of navigational officers, NACOS trainers did not discuss the issue before the *Crown Princess* accident (see "Shallow Water Effects" section). After the accident, SAM Electronics modified its NACOS software so that it will warn operators when vessel speed is excessive for water depth. A warning is given for decreasing water depth and an alarm is sounded for shallow water at high speed. The warnings are based on formulas developed in a postaccident study, as detailed in the "Shallow Water Effects" section. SAM Electronics modified its training material to instruct students about the warnings.

Princess Cruises sent its watchkeeping deck officers to the Carnival Corporation training center in Southampton for NACOS training conducted by an employee that SAM Electronics certified to serve as a NACOS trainer. Deck officers on the *Crown Princess* were trained both at the SAM Electronics Bremen facility and at Southampton. Princess Cruises required captains to interview all deck officers assigned to a vessel for the first time in order to verify their understanding of and familiarity with the NACOS and other vessel systems.

Princess Cruises personnel estimated that in the 2 years before the accident, as many as six crewmembers were directed to receive additional NACOS training. Either a vessel captain or a supervisor had recommended the additional training after reading the VDR in response to a concern about vessel operation. Company policy called for monitoring the VDR of a voyage after a concern about vessel operation was reported.

In response to heeling incidents and other occurrences on its vessels, Holland America Line reviewed its operations and modified its bridge resource management class. The curriculum, while adhering to content requirements of the STCW code, featured simulator-based scenarios taken from actual incidents and accidents on the cruise line. Students in the class, all company deck officers, were presented with the scenarios and observed for the quality of their responses. Data on vessel position, speed, proximity to other vessels, weather and sea conditions, and the like were taken from actual events, with modifications to reduce the likelihood that students would recognize a specific event. Students were sent to the facility every 5 years, and the scenarios were scheduled to be modified on a 5-year cycle so that students would not be presented with the same scenarios in successive classes.

Royal Caribbean International also reviewed its heeling incidents and created a lessons-learned exercise for deck officers based on selected incidents. The company described the incidents and highlighted crewmember errors leading to the incidents. The objective of the exercises was for deck officers to apply the lessons learned from the incidents to enable them to avoid similar errors.

Previous Board Action. On August 7, 1992, the United Kingdom–registered vessel *QE2* was outbound in Vineyard Sound, Massachusetts, when it grounded about 2 ½ miles south of Cuttyhunk Island. No injuries or deaths resulted from the accident, but the vessel sustained significant damage. The Safety Board determined that the probable cause of the grounding was the errors in communication made by the pilot, master, and watch officers regarding a navigation plan for departing Vineyard Sound and their failure to maintain situation awareness regarding vessel navigation after an unplanned course change. Contributing to the accident was "the lack of information available on the *Queen Elizabeth 2* about how speed and water depth affect the ship's underkeel clearance."[78]

The Board's investigation found that the vessel's master and pilot, while generally aware of the phenomenon of squat on vessels operating at high speed in shallow water, had underestimated the effects of squat on the *QE2*. After the vessel cleared local marine traffic and headed toward the open ocean, the master, with the pilot's agreement, directed the speed to be increased to 25 knots so the vessel would arrive in New York on schedule.

The pilot asked for a course change to the right of the intended course. The second officer, who was on the bridge, observed that the projected path of the vessel would cross a shoal area and informed the captain (through the first officer). The captain expressed his concern to the pilot, who ordered a course change south of the projected track. The second officer noticed that the new trackline would pass over a 6-½-fathom (39-foot) sounding but did not express his concern. Both the pilot and the master considered the 39-foot sounding, with the tide of plus 1 ½ feet, to be sufficient for safe vessel passage. Neither recognized that the effects of the high vessel speed over the relatively shallow water would lead to the squat that caused the vessel to ground on the 39-foot shoal. Their lack of recognition may have been the result of the lack of widespread distribution of information regarding squat effects on vessel motion.

As a result of its investigation of the *QE2* accident, the Safety Board made the following recommendation to the Coast Guard:

[78] National Transportation Safety Board, *Grounding of the United Kingdom Passenger Vessel RMS* Queen Elizabeth 2 *Near Cuttyhunk Island, Vineyard Sound, Massachusetts, August 7, 1992*, Marine Accident Report NTSB/MAR-93/01 (Washington, DC: NTSB, 1993).

M-93-23

> Widely publicize the particulars of this accident concerning the large squat for ships operating at high speeds in shallow waters.

In response, the Coast Guard commandant, on September 27, 1993, wrote:

> I concur with this recommendation. Copies of the Coast Guard's investigation report on this casualty are being provided to IMO [International Maritime Organization] to disseminate the research information regarding vessel squat. In addition, we will develop material for publication in a Notice to Mariners, Proceedings of the Marine Safety Council, or other maritime publications. I will provide copies of the articles to the Board when published.

The Coast Guard disseminated information about the accident, specifically about the crew's knowledge of squat effects, within the marine community. The accident was a cover story in a 1993 Coast Guard publication distributed to professional mariners. As a result of the Coast Guard's action, on March 20, 1997, the Safety Board classified Safety Recommendation M-93-23 as "Closed—Acceptable Action."

Three years later, on June 10, 1995, the Panamanian-registered vessel *Royal Majesty* grounded approximately 10 miles east of Nantucket Island, Massachusetts, about 17 miles west of its intended track.[79] None of the 1,509 persons on board was injured, but the vessel sustained several million dollars worth of damage. The Safety Board determined that the probable cause of the accident was the deck officers' overreliance on the vessel's INS,[80] Majesty Cruises's failure to ensure that its deck officers were adequately trained in the automated features of the INS and in the implications of this automation for the INS, deficiencies in the design and implementation of the INS and in its operational procedures, and errors the second officer committed in failing to detect cues that the vessel was off course.

The *Royal Majesty* had been equipped with a NACOS 25 (the NACOS version STN Atlas was manufacturing at the time) that included an autopilot integrated with radar information, presented through an ARPA display that could steer the vessel along a track of selected navigation points (similar to the trackpilot, track mode, on the *Crown Princess*'s NACOS 65-5). The vessel, which obtained position data from both GPS and LORAN,[81] began to deviate from its intended course after the cable connecting the GPS antenna to the receiver separated and the GPS automatically reverted to dead reckoning without bridge watchkeepers

[79] National Transportation Safety Board, *Grounding of the Panamanian Passenger Ship* Royal Majesty *on Rose and Crown Shoal Near Nantucket, Massachusetts, June 10, 1995*, Marine Accident Report NTSB/MAR-97/01 (Washington, DC: NTSB, 1997).

[80] Note that in its report, the Safety Board used the term IBS rather than INS.

[81] LORAN (LOng RAnge Navigation) is a ground-based navigation system using low-frequency radio transmitters for transoceanic navigation.

recognizing the change. The GPS did not signal the INS that it had reverted to dead reckoning, nor was it required to.

At the time of the accident, Majesty Cruises offered NACOS training to its deck officers through on-the-job training, under the supervision of the vessel's navigator. The cruise line provided simulator sessions to deck officers to practice navigation using the INS, but it did not make training checklists available to the navigators who provided on-the-job training. STN Atlas had offered training in the use of NACOS to its customers, but Majesty Cruises did not order or receive such training.

As a result of its investigation of the *Royal Majesty* accident, the Safety Board issued the following recommendation to the Coast Guard:

> M-97-5
>
> Propose to the International Maritime Organization that it develop appropriate performance standards for the training of watch officers assigned to vessels equipped with integrated bridge systems and require this training.

In response, on November 6, 1998, the Coast Guard wrote:

> We do not concur with this recommendation. The fact that the watch officers in this incident did not perform their watchkeeping duties properly does not establish a need for special international standards of training for watch officers on vessels equipped with integrated bridge systems. There is no indication that the existing international standards of qualification are inadequate. The 1995 amendments to the International Convention on Standards of Training, Certification, and Watchkeeping for Seafarers, 1978, (STCW) provide ample international standards and regulations which, if followed, would prevent incidents such as the grounding of the *Royal Majesty*. For example, regulation 1/14, STCW requires a company that owns or operates a ship to ensure that "seafarers, on being assigned to any of its ships, are familiarized with their specific duties and with all ship arrangements, installations, equipment, procedures, and ship characteristics that are relevant to their routine or emergency duties."
>
> Officers in charge of a navigational watch are required to have the "ability to determine the ship's position by use of electronic navigational aids," and one criterion to evaluate the officer's competence in navigation is that "the reliability of the information obtained from the primary method of position fixing is checked at appropriate intervals." Watchkeeping requirements specify that "during the watch, the course steered, position and speed shall be checked at sufficiently frequent intervals, using any available navigational aids necessary, to ensure that the ship follows the planned route." STCW also requires that masters and chief mates be proficient in effective bridge teamwork procedures.
>
> We anticipate that the 1995 STCW amendments, combined with the requirements of the International Safety Management code (ISM code),

> will improve watchkeeping practices. The Coast Guard plans no further action on this recommendation, and requests that it be closed.

Because the Coast Guard planned no action on the recommendation, on April 20, 1999, the Safety Board classified Safety Recommendation M-97-5 as "Closed—Unacceptable Action."

Also as a result of the *Royal Majesty* accident, the Safety Board issued the following recommendation to the ICCL:

> M-97-21
>
> Recommend that its members provide initial and recurrent formal training on essential technical information, equipment functions, and system operating procedures to all bridge watchstanding personnel on their ships that are equipped with integrated bridge systems.

In its response of October 11, 1999, the ICCL wrote:

> ICCL member lines provide initial and recurrent formal training to their bridge personnel through "in-house" initial training/familiarization programs and recognized shoreside crew training facilities such as the Star Center in Dania, FL, and Marine Safety in Rotterdam. ICCL member vessels comply with the International Maritime Organization (IMO) requirements for crew training and certification. The International Convention, Standards of Training, Certification and Watchkeeping (STCW), sets the minimum standards for the training and certification of crew members onboard all vessels engaged in international voyages. Further, independent authorities, in accordance with the International Safety Management code (ISM) certify all ICCL member lines. This system ensures that the training, watch standing practices and procedures are in accordance with accepted international maritime practices.

On March 21, 2000, the Safety Board responded to the ICCL, classifying Safety Recommendation M-97-21 as "Closed—Reconsidered":

> While the ICCL did not provide information on how it recommended, encouraged, or advised its members as requested, the Safety Board understands that these recommendations were discussed and reviewed in detail at the ICCL's technical committee meeting in July 1999. The Safety Board notes that member companies have implemented some of these recommendations. As stated in our February 19, 1999, letter, and as discussed at the Safety Board/ICCL meeting this past fall, the Safety Board understands that the ICCL does not make recommendations to its membership. Therefore, the Safety Board will address future recommendations to the individual cruise ship companies that are affected.

Analysis

General

The analysis first identifies factors that can be eliminated as causal or contributory to the accident. It then discusses the following safety issues identified in the accident investigation:

- Actions of captain, staff captain, and second officer.
- Training in use of integrated navigation systems.
- Reporting of heeling incidents and accidents.
- Emergency response following severe incidents.

Exclusions

The *Crown Princess* had been in service only a month at the time of the accident. The vessel's steering and propulsion systems and NACOS were tested during sea trials before the accident, as well as in tests conducted after the accident. Both pre- and postaccident testing found that the systems performed as designed. The weather and sea state were mild and unlikely to have affected the vessel's performance.

Toxicological analysis of samples taken from the deck officers on duty during the accident were negative for the presence of alcohol and illegal drugs, and the officers had maintained regular sleep and work schedules in the days before the accident. Therefore, the Safety Board concludes that the following were not factors in the accident: vessel's mechanical condition, weather, sea state, and behavioral or physiological impairment of the crew.

Accident

The *Crown Princess*'s departure from Port Canaveral was uneventful. The pilot had the conn at departure and the crew steered the vessel manually. After the pilot disembarked and the vessel entered the open ocean, the crew engaged the trackpilot and the captain ordered an increase in the vessel's speed to stay ahead of forecast adverse weather. The captain and staff captain left the bridge, turning the navigation watch over to the second officer. The second officer, concerned by indications of a high rate of turn to port, disengaged the trackpilot and began steering the vessel manually. His first turn was opposite to his intended direction. A minute later, the vessel heeled hard to starboard. The heeling caused passengers and crew to strike the vessel's structure or objects on the vessel or to be struck by objects, resulting in almost 300 injuries. The *Crown Princess* was traveling at 20 knots, nearly full speed, when it heeled. The vessel was in relatively shallow water at the time of the accident, with 8.3 meters (about 26 feet) of water under the keel.

Actions of Captain and Staff Captain

According to information from both the VDR and interviews of the captain, staff captain, and second officer, about 1503 the vessel's heading began to fluctuate around its designated 100° heading. Two minutes later, the trackpilot rudder limit alarm sounded. In response, the staff captain increased the rudder limit from 5° to 10°. At the time, the rudder economy was set to level 5, normally intended for rough seas.

The captain and staff captain, both experienced mariners, should have realized that because the vessel was operating in relatively shallow water, its response to rudder movements would lessen and its maneuverability become unpredictable. The trackpilot, whose performance was predicated on deep-water vessel characteristics, would likewise perform unpredictably in shallow water at high speeds. These hydrodynamic effects were so obvious to SAM Electronics that its representatives told Safety Board investigators that they saw no need to address the topic in their NACOS training. They assumed that, irrespective of experience, all mariners would be aware that operating at high speed in shallow water would affect vessel performance. Both the captain and the staff captain, despite their experience, apparently failed to recognize that the INS would be unpredictable at a speed of 20 knots in waters 8 meters deep under the keel. The Safety Board therefore concludes that the captain and staff captain did not recognize that high speed and shallow water were adversely affecting the vessel's course stability.

In addition to the effects on vessel steering of high speed in shallow water, the staff captain further enabled the vessel's course deviations by increasing the rudder limit while maintaining the trackpilot's rudder economy setting at level 5. As described in the NACOS operating manual, the selection of the rudder economy limit was to be based on the sea state and weather conditions. Level 5 was to be used when conditions were "bad," according to the manual. Rudder economy settings allow increases in vessel heading fluctuations with increases in the rudder economy level. Such increases are desirable in rough seas but not in calm seas, where large rudder motion can increase passenger discomfort and wear and tear on the steering system.

Neither the staff captain nor the captain appears to have recognized that the rudder economy setting was related to the rudder limit alarms that had led the officers to increase the rudder limit. They should have understood that the rudder economy had been set to a level inappropriate to the operating conditions (sea state). When the captain said, "We're wandering all over the place," neither he nor the staff captain seemed to realize that the "wandering" was influenced by the vessel's high speed in relatively shallow water and was exacerbated by the rudder economy setting. Increasing the rudder limit, particularly given the inappropriate rudder economy setting, was inappropriate as well because it allowed greater heading fluctuations. The proper response to the rudder limit alarm, given the sea state and operating conditions, would have been to assess the cause of the alarm, that is, the inappropriate rudder economy setting, and readjust the setting to the appropriate level. The Safety Board therefore concludes that the captain and staff captain inappropriately adjusted the trackpilot's rudder limit in response to unintended deviations in the vessel's set heading, and they failed to adjust the rudder economy setting, which was inappropriate for the sea state and was exacerbating the course deviations.

The captain turned the conn over to the second officer at 1518, 6 minutes before the second officer disengaged the trackpilot. However, the fluctuations in the vessel's heading that the captain and staff captain had attempted to address through the INS continued, leading the second officer to attempt to correct them by taking manual control of the steering. The captain transferred the conn without determining the cause of the heading fluctuations, and worse, left the bridge without verifying that they were lessening. The evidence of his previous experience as captain and his actions in turning over the conn suggest that the captain believed either that the INS would stabilize the heading or that the second officer would remedy the problem. However, neither outcome was realized. The Safety Board therefore concludes that the captain should not have transferred the conn to the second officer and left the bridge unless he could verify that the vessel's heading fluctuations had diminished.

Second Officer's Actions

The *Crown Princess* was operating at nearly full speed when the second officer took the conn. He immediately faced the problem of navigating a vessel that exhibited both increasing course deviations and high rates of turn. The second officer told investigators that his eyes "were instantly drawn to" the red color of the rate-of-turn indicator on the bridge, which indicated a high rate of turn to port. He responded immediately by disengaging the trackpilot[82] and turning the wheel 10° to port, when he should have turned it to starboard to counteract the turn.

After his initial turn to port, the second officer manually steered back and forth between port and starboard in increasingly wider turns. Rather than remedying the problem, the second officer's actions exacerbated the course fluctuations and high turn rates, and caused larger and larger heel angles. The result was an increasing heel to starboard that eventually peaked at about 24°.

[82] Disengaging the trackpilot disengaged the rudder limit and rudder economy settings.

As detailed in the "Vessel Dynamics" section, the second officer moved the wheel faster than the rudders could follow. Numerous cues were available to inform the second officer that the vessel was not responding as he commanded or expected. Visual cues came both from what he could see outside the window and from bridge instruments that indicated the vessel's rate of turn and course. In addition, he would have received vestibular cues about angular acceleration. That is, he would have felt the speed with which the vessel was heeling and turning.

The second officer's three turns to port temporarily slowed the rate of heel. However, the overall effect was to increase the heel to starboard, because, as shown in figure 7, the rudders remained to port and the vessel's drift angle (the difference between its heading and its track) continued to increase. Thus, after his initial command to port, each time the second officer commanded rudder movements, the heel rate temporarily slowed, giving the perception of correcting the starboard heel angle. However, this effect was at the overall expense of a greater starboard heel angle, a result that contradicted the desired outcome. That is, the second officer's wheel inputs increased the starboard heel over the duration of the event rather than decreasing it. It could not be determined whether the second officer's initial turn was due to a "slip"[83] or to a misdiagnosis of the situation.

Because the second officer was, as he stated, "instantly drawn to" the red color on the rate-of-turn indicator, and because the vessel did not respond as he expected, he reacted in a manner consistent with someone under stress. Stress would have limited the second officer's ability to diagnose and respond effectively to the situation he faced. As has been observed: "Stress narrows people's field of attention to a limited number of central aspects. Under perceived danger, a decrease in attention has been observed for peripheral information."[84] The second officer, according to what he told investigators, focused almost exclusively on the vessel's rate of turn. The second officer's repeated turns of the wheel thereafter were futile and inappropriate attempts to slow the turn rate and correct the heeling. His activity only made the situation he faced worse, his stress level higher, and his ability to comprehend and respond appropriately to the situation he faced more difficult.

In such circumstances, a crewmember who was fully aware of the situation would most likely have taken two actions—held a steady course, and reduced speed. Because of the second officer's inappropriate steering, the turn rate increased and the vessel heeled hard to starboard. The relief captain was the first person to return to the bridge when the vessel began heeling and immediately ordered, "Reduce the speed." Slowing the vessel, in addition to disengaging the trackpilot, was a course of action that the second officer, as an experienced mariner, should have known to take in response to a possible steering failure.

[83] The second officer's initial turn to port, when he meant to turn to starboard, can be considered an error of execution. James Reason (*Human Error* [New York: Cambridge University Press, 1990]) refers to such an error as a "slip," a relatively minor error that contrasts with a high-level cognitive error such as misdiagnosing a situation. In a slip, a person means to do one thing, but the execution differs from the person's intention.

[84] M. R. Endsley, "Toward a Theory of Situation Awareness," *Human Factors* 37 (1995), p. 52.

The Safety Board concludes that the *Crown Princess* heeled because, after the second officer disengaged the trackpilot and turned the wheel to port rather than turning it to midships and slowing the vessel as he should have, his subsequent steering commands to both port and starboard, at angles ranging from 10° to 45°, led to vessel responses that he did not expect, did not understand, and was therefore unable to correct.

The Safety Board examined the second officer's training and experience to determine whether deficiencies in either might have played a role in his performance during the accident. His training in the British maritime academy was equivalent to that of the other British-trained deck officers that Princess Cruises employed, and his record indicates that he would have been exposed to the same training scenarios as other British students in maritime training at that time. His experience, which was entirely with Princess Cruises and a predecessor company, was consistent with that of a second officer who had been out of school for 6 years. In addition, the record indicates that he performed satisfactorily in his training and as a deck officer. Thus, there was no evidence of shortcomings in his training or background and no evidence that he performed less than satisfactorily in either. Therefore, the Safety Board concludes that no deficiencies in the second officer's training or background could account for his inappropriate steering commands.

Training in Use of Integrated Navigation Systems

The captain and staff captain of the *Crown Princess* made several errors with regard to the INS trackpilot. Specifically, they failed to recognize the following:

- Effects of high vessel speed in shallow water on course stability.
- Effects of rudder economy level 5 on rudder performance.
- Effects on fluctuations around the heading of increasing the rudder limit from 5° to 10°.

In examining other heeling accidents and incidents, the Safety Board found common antecedents—crewmembers not fully understanding the INS they were using, not anticipating the effect of their actions on the INS, or both. Integrated navigation systems, whether manufactured by SAM Electronics, Sperry Marine, or another company, are sophisticated devices that monitor, display, and control considerable information about a vessel's position, direction, and path, the sea state in which it operates, and related information about nearby vessels. The systems integrate previously developed individual components (such as AIS, ARPA, and ECDIS) with steering to allow the display of information and control of components at a single workstation. The systems also offer options as to the amount and type of information presented and the type of vessel navigation and control desired. As both hardware and software technology have advanced, designers have added capabilities to the systems, further increasing an operator's choices in information and vessel control.

The Safety Board found shortcomings in training that may have contributed to the errors in INS use that played a role in some of the other heeling incidents reviewed in this investigation. For example, under the current system, completing INS training does not assure mastery of the system because students are not required to demonstrate mastery of an INS at the completion of many formal INS training programs.

Given the amount of information an INS can present and its many control and display options, a crewmember who completes INS training and then does not use the system on a vessel for several years may not remember much of the class material or be able to apply it. Further, neither the Coast Guard nor the International Maritime Organization requires licensed mariners to complete formal INS instruction before using an INS. There is also no requirement that mariners who have completed INS instruction take courses thereafter. A system that allows users to interact with such sophisticated systems as an INS with the training shortcomings noted is deficient and increases the likelihood that crewmembers will commit INS-related errors. The Safety Board therefore concludes that the errors of the captain and staff captain in operating the INS resulted from inadequate training.

The Safety Board identified deficiencies in INS training 10 years earlier in its investigation of the grounding of the *Royal Majesty* and issued Safety Recommendation M-97-5 to the Coast Guard. The Coast Guard disagreed with the recommendation, and the Safety Board classified it as "Closed—Unacceptable Action."

Since the Safety Board issued its recommendation, errors in INS use have continued. Although in recent years the International Maritime Organization has recognized the need for additional attention to INS training for bridge watch officers, the training is still not mandatory. The record of passenger vessel incidents and accidents related to deficiencies in INS training since the *Royal Majesty* accident contradicts the outcome foreseen by the Coast Guard when it responded to Safety Recommendation M-97-5 that "there is no indication that the existing international standards of qualification are inadequate" and that "the 1995 amendments to the international convention on standards of training, certification, and watchkeeping for seafarers, 1978 (STCW) provide ample international standards and regulations" governing INS training.

The International Maritime Organization has developed a model training curriculum for INS and IBS equipment (appendix E). The curriculum, which is advisory only, addresses many of the shortcomings in INS training requirements that the Safety Board noted in its investigation of the *Crown Princess* accident. For example, it details a 40-hour class, with instructional objectives related to INS/IBS use, and devotes segments of class time to particular topics. In addition, it suggests simulator exercises to allow students to apply the information addressed in class and offers guidance on testing or evaluating a student's knowledge at course end.

However, because there is no international requirement for INS training, the proposed model curriculum may not be effective in addressing the shortcomings in INS training noted in this investigation. Until crewmembers are required to demonstrate mastery of INSs and IBSs through formal, well-designed training programs, there can be no assurance that watchkeepers are proficient in the use of these sophisticated systems. The model International Maritime Organization curriculum, or other training endeavors that meet similar instructional objectives, if implemented and made mandatory with mariner participation in the training, would increase the likelihood that crewmembers will use INS or IBS equipment effectively in all operating conditions. Therefore, the Safety Board believes that the Coast Guard should propose to the International Maritime Organization that, in conjunction with the upcoming revisions to the STCW, it make training in INS and IBS mandatory for watchkeepers on vessels equipped with such systems.

As a result of the *Royal Majesty* accident, the Safety Board issued recommendation M-97-21 to the ICCL, now the Cruise Lines International Association (CLIA). The ICCL did not agree with the Safety Board, citing the training its members received at shoreside training facilities and the adequacy of STCW requirements and ISO certification. The Safety Board accepted the ICCL's stated inability to recommend particular courses of action to its members. In the Safety Board's opinion, however, the *Crown Princess* accident indicates that passenger cruise lines should ensure that all deck officers are thoroughly versed in INS operations. The Board recognizes that it will take time for the International Maritime Organization to mandate INS training. Therefore, the Safety Board believes that, until the International Maritime Organization makes INS training mandatory, CLIA should recommend to its members that they voluntarily provide initial and recurrent training in INS operation to crewmembers having watchkeeping responsibilities on vessels equipped with such systems, and include in that training a requirement for a demonstrated level of proficiency.

Further, the circumstances of this accident suggest that even experienced deck officers may not recognize how operating at high vessel speed in shallow water can affect rudder, vessel, and INS performance. In its investigation of the 1992 *QE2* grounding, the Safety Board found that the crewmembers lacked knowledge of shallow water effects on their vessel. (They were operating off the coast of Massachusetts at a speed of 25 knots.) As a result, the Safety Board issued Safety Recommendation M-93-23 to the Coast Guard, which it classified as "Closed—Acceptable Action" after the Coast Guard publicized the circumstances of the accident. Partly because of this action, information on squat was prominently posted on the *Crown Princess* bridge.

Nonetheless, the circumstances of the *Crown Princess* accident suggest that the officers, while familiar with squat, did not recognize that high vessel speed in shallow water could also adversely affect the precision of vessel steering. In addition, the second officer's actions indicate that he lacked the emergency ship-handling skills that would have allowed him to respond effectively to the vessel's unexpected behavior. The Safety Board is concerned that other officers in charge of the navigational watch may also be unprepared for serious, unexpected incidents such as a vessel heeling. Therefore, the Safety Board believes that the CLIA should, through its website, publications, and conferences, inform its members about the circumstances of this accident and urge them to incorporate into their safety management systems and training programs for officers in charge of the navigational watch (1) information about the effects on vessel performance of high-speed vessel operations in shallow water, and (2) initial and recurrent training for emergency ship-handling scenarios based on the lessons learned from serious marine incidents and accidents.

After the *Crown Princess* accident, SAM Electronics addressed shortcomings in its NACOS training by including in its material specific references to shallow-water effects on INS performance. Before the accident, the company had assumed that mariners did not need such instruction because they were already knowledgeable about shallow-water effects, but that assumption proved to be mistaken. The manufacturer's action of adding an alarm to signal the bridge when a vessel is entering shallow water at high speed should help avoid situations that diminish vessel maneuverability and INS performance such as the *Crown Princess* experienced.

After the accident, Princess Cruises required senior deck officers to repeat bridge resource management courses and provided all deck officers with additional NACOS training. Princess Cruises also urged its personnel to place user-friendly guidance from bridge operations manuals in readily accessible locations on vessel bridges. While there is no evidence that the complexity or inaccessibility of the NACOS manual or other operations manuals affected the crew's actions in the *Crown Princess* accident, making equipment guidance easier to use and more accessible could enhance crew response in future unexpected or nonroutine situations.

Holland America Line and Royal Caribbean have also taken steps to improve the training of their deck officers, such as developing lessons-learned programs based on previous heeling incidents.

Postaccident Crew Response

With almost 300 passengers and crew injured on the *Crown Princess*, the captain's quick decision to return to port enabled injured passengers and crewmembers to be treated at shoreside medical facilities. The ship's medical personnel helped those in need with transport to shoreside medical facilities. Before the vessel reached the dock, the medical team established a triage of the injured, identified and treated the most seriously injured, and communicated to the captain the severity of the injuries. Therefore, the Safety Board concludes that the captain acted properly in returning to Port Canaveral after the accident, and that the crew responded effectively in administering medical care to the injured.

The Safety Board examined the captain's decision not to muster passengers after the accident. The captain told investigators that, shortly after the accident, he checked with the two bridge lookouts who were monitoring for balcony fires, and they informed him that they had not seen anyone fall overboard. Therefore, the captain decided not to ask the passengers to report to their muster stations but, rather, told them to report to their cabins.

Directing passengers to report to their muster stations would certainly have enabled the crew to account for the passengers. However, although the captain did not say so, it is unlikely that anyone would have fallen overboard unnoticed because many passengers and crew were on the outside decks in the bright, mid-afternoon daylight conditions. Further, given the debris on the vessel after the accident, including water from the pools, broken glass, and displaced and overturned furniture, directing passengers to their muster stations could have exposed them to hazards of slips, falls, and blunt or lacerating injury. In addition, the number of injured passengers and crew and the severity of their injuries were uncertain. Having passengers report to muster stations could have delayed treatment of the injured. Therefore, the Safety Board concludes that the captain's decision not to order passengers to their muster stations after the accident was appropriate.

The captain's decision, while appropriate under the circumstances of the *Crown Princess* accident, might be inappropriate under other circumstances. After the accident, Princess Cruises implemented the use of a new technological aid for the accounting of passengers after an emergency. The aid should reduce the burden on crewmembers of attempting to account for all passengers while they are busy responding to the aftereffects of an incident.

Monitoring of Heeling Incidents

The investigation found that there is no systematic way of providing information or feedback regarding INS- or IBS-related incidents to the system designers or trainers. The current system, by which companies learn of incidents through media reports or directly from a cruise line, is informal and unsystematic. Further, it does not provide manufacturers with complete data on how their systems are used or misused.

Manufacturers focus primarily on data that inform them of hardware or software flaws. That information, while important, provides an incomplete account of actual operations. Worse, neither designers nor trainers may learn of incidents that could lead to design or training changes because there is no system of reporting such incidents.

Data on errors in INS or IBS use may point to flaws in the system interface or suggest areas of improvement in the system design or training. Without such information, manufacturers have no reliable method of learning whether their products are being used as intended and whether their products or training programs are meeting their objectives. The Safety Board therefore concludes that the systematic collection of data on mishaps related to INSs and IBSs will enhance the systems' design, procedures, and training. Therefore, the Safety Board believes that SAM Electronics and Sperry Marine should work with cruise lines and other vessel operators to develop a system that provides them with critical information regarding errors or potential problems in the use of INSs or IBSs and apply the lessons learned to system design and crew training.

Safety Board investigators determined the *Crown Princess*'s maximum angle of heel from images taken by videocameras installed on the vessel for purposes other than accident investigation. The VDR, which was designed to collect data for use in accident investigations, did not record heel angles. There is no requirement for VDRs to record heel angles. The vessel's IMAC retained heeling data, but only measured angles of heel between starboard 15° and port 15°. Data that accurately record a vessel's angle of heel can considerably assist those attempting to understand the nature of a heeling event. The Safety Board therefore concludes that the *Crown Princess* accident demonstrates the need for obtaining and archiving data on vessel angles of heel. Consequently, the Safety Board believes that the Coast Guard should propose to the International Maritime Organization that it mandate the recording on VDRs of heel angles through the complete range of possible values.

Conclusions

Findings

1. The following were not factors in the accident: vessel's mechanical condition, weather, sea state, and behavioral or physiological impairment of the crew.

2. The captain and staff captain did not recognize that high speed and shallow water were adversely affecting the vessel's course stability.

3. The captain and staff captain inappropriately adjusted the trackpilot's rudder limit in response to unintended deviations in the vessel's set heading, and they failed to adjust the rudder economy setting, which was inappropriate for the sea state and was exacerbating the course deviations.

4. The captain should not have transferred the conn to the second officer and left the bridge unless he could verify that the vessel's heading fluctuations had diminished.

5. The *Crown Princess* heeled because, after the second officer disengaged the trackpilot and turned the wheel to port rather than turning it to midships and slowing the vessel as he should have, his subsequent steering commands to both port and starboard, at angles ranging from 10° to 45°, led to vessel responses that he did not expect, did not understand, and was therefore unable to correct.

6. No deficiencies in the second officer's training or background could account for his inappropriate steering commands.

7. The errors of the captain and staff captain in operating the integrated navigation system resulted from inadequate training.

8. The captain acted properly in returning to Port Canaveral after the accident, and the crew responded effectively in administering medical care to the injured.

9. The captain's decision not to order passengers to their muster stations after the accident was appropriate.

10. The systematic collection of data on mishaps related to integrated navigation systems and integrated bridge systems will enhance the systems' design, procedures, and training.

11. The *Crown Princess* accident demonstrates the need for obtaining and archiving data on vessel angles of heel.

Probable Cause

The National Transportation Safety Board determines that the probable cause of the *Crown Princess* accident was the second officer's incorrect wheel commands, executed first to counter an unanticipated high rate of turn and then to counter the vessel's heeling. Contributing to the cause of the accident were the captain's and staff captain's inappropriate inputs to the vessel's integrated navigation system while the vessel was traveling at high speed in relatively shallow water, their failure to stabilize the vessel's heading fluctuations before leaving the bridge, and the inadequate training of crewmembers in the use of integrated navigation systems.

RECOMMENDATIONS

As a result of its investigation of this accident, the National Transportation Safety Board makes the following safety recommendations.

To the U.S. Coast Guard:

> Propose to the International Maritime Organization that, in conjunction with the upcoming revisions to the Standards of Training, Certification, and Watchkeeping for Seafarers, it make training in integrated navigation systems and integrated bridge systems mandatory for watchkeepers on vessels equipped with such systems. (M-08-1)

> Propose to the International Maritime Organization that it mandate the recording on voyage data recorders of heel angles through the complete range of possible values. (M-08-2)

To the Cruise Lines International Association:

> Until the International Maritime Organization makes training in integrated navigation systems mandatory, recommend to your members that they voluntarily provide initial and recurrent training in integrated navigation system operation to crewmembers having watchkeeping responsibilities on vessels equipped with such systems, and include in that training a requirement for a demonstrated level of proficiency. (M-08-3)

> Through your website, publications, and conferences, inform your members about the circumstances of this accident and urge them to incorporate into their safety management systems and training programs for officers in charge of the navigational watch (1) information about the effects on vessel performance of high-speed vessel operations in shallow water, and (2) initial and recurrent training for emergency ship-handling scenarios based on the lessons learned from serious marine incidents and accidents. (M-08-4)

To SAM Electronics and Sperry Marine:

> Work with cruise lines and other vessel operators to develop a system that provides you with critical information regarding errors or potential problems in the use of integrated navigation systems or integrated bridge systems and apply the lessons learned to system design and crew training. (M-08-5)

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

Mark V. Rosenker
Chairman

Robert L. Sumwalt
Vice Chairman

Deborah A. P. Hersman
Member

Kathryn O'Leary Higgins
Member

Steven R. Chealander
Member

Adopted: January 30, 2008

Member Hersman filed the following dissenting statement on January 15, 2008.

Notation 7963B

Member Hersman, Dissenting:

I voted against Recommendation #1 to the Coast Guard to propose that IMO make training in INS and IBS mandatory for watchkeepers on vessels equipped with such systems because I do not believe it addresses the shortcomings identified in this accident investigation.

Our report very clearly states that the NTSB believes that mariners should be required to take INS training, yet at the same time, we acknowledge that such training may be ineffective if mariners cannot demonstrate mastery of the subject matter or currency. In this case, the crew had all received INS training at the manufacturer's facility: the Captain completed a 3-day course in 1997; the Staff Captain completed a 4-day course in 2002; and the Second Officer completed a 3-day course in 2004. Nevertheless, our report concludes, "The errors of the captain and staff captain in operating the INS resulted from inadequate training." Moreover, our investigators' analysis found shortcomings in INS training that may have contributed to errors that played a role in other heeling incidents reviewed in this investigation.

Under the current system, completing INS training does not assure mastery of the system because students are not required to demonstrate mastery of an INS at the completion of most formal INS training programs. Further, neither the Coast Guard nor the IMO require licensed mariners who have completed initial INS training take courses thereafter. Because this crew had received training, our recommendation to require training without addressing competency and currency does not fully address the concerns identified in the report and would not prevent a similar event from recurring.

At the Board meeting on January 10, my colleagues were reluctant to include competency and currency training in our recommendation to the Coast Guard because that would be asking for too much too soon. There was the argument that the IMO must first establish through delicate negotiations with many other countries a requirement for mandatory INS training before it can entertain a suggestion by the Coast Guard to also require a demonstration of proficiency or recurrent training. While I understand the sensitivity of the Coast Guard's position with the IMO regarding any such recommendation, I also do not believe it is our role to determine what the negotiating posture of the Coast Guard should be. Our report seems to build an argument for a fuller, more inclusive, recommendation. I believe we should have put forth the more inclusive recommendation, leaving it up to the Coast Guard to determine what it will encourage the IMO to accomplish.

I note that the IMO has already developed an INS/IBS "model course." In addition, in 2006, the IMO's Subcommittee on Standards on Training and Watchkeeping (STW) considered the need for a comprehensive review of the Seafarer's Training, Certification, and Watchkeeping (STCW) Convention and the STCW code, and proposed INS/IBS training as a work item with a target completion of 2008. In an effort to not ask for too much, our new recommendation may be asking for something already underway, and perhaps it is asking for even less than what is already underway.

The NTSB determines what happened in an accident and, as an independent voice of safety, recommends changes to prevent future accidents. It is up to others (industry, labor, regulators, government officials) to determine whether or not to adopt our recommendations. We are not the regulator bound by cost-benefit analysis, nor are we the international negotiator bound by political concerns. If we begin to anticipate how the recipients of our recommendations will respond, and modify our recommendations according to what can be accomplished in the near term, we are neglecting to promote broader safety initiatives that can be accomplished in the long term. As the sentinels of safety, we must issue candid and uncensored recommendations designed to encourage safety improvements for the immediate future as well as for many years to come.

Deborah A. P. Hersman
January 15, 2008

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Appendix A

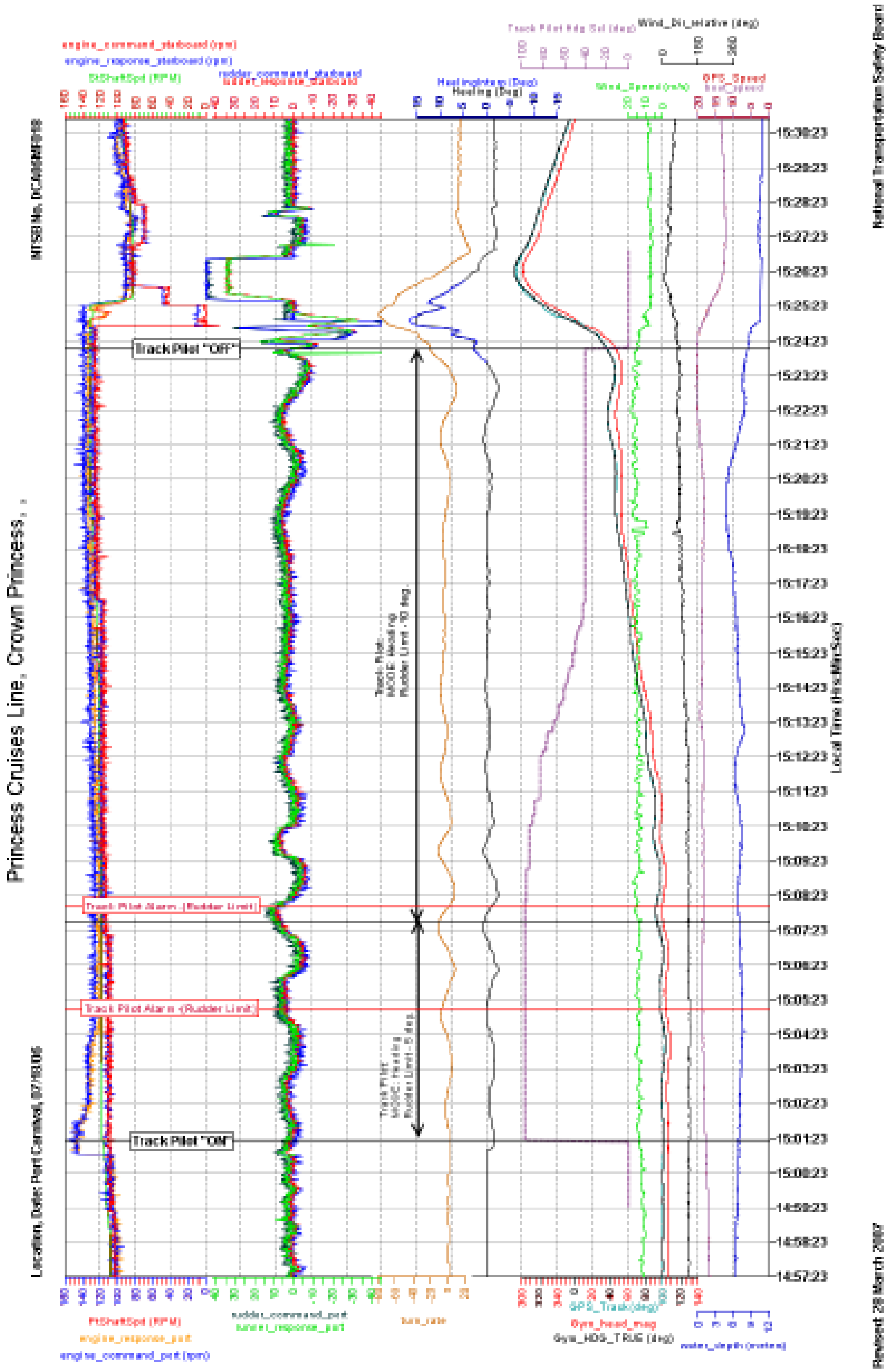
Investigation

The Safety Board was notified of the *Crown Princess* accident by the Board's communication center at 1725 on July 18, 2006. The Board launched a team of three investigators from Washington, DC, to Port Canaveral, Florida. The investigator-in-charge arrived the evening of July 18, boarded the ship, and retrieved the data from the vessel's voyage data recorder. The next morning, the two other Board investigators (specialists in marine engineering and survival factors) arrived and joined investigators from the U.S. Coast Guard on board the ship. The team was later joined by a representative of Bermuda, the vessel's flag state. No Board Member traveled to the scene. The investigative team interviewed witnesses, including the officers on the bridge watch at the time of the accident, and traveled with the crew and others on a postaccident test of the vessel's navigation and steering equipment on July 20 and 21. The on-scene investigation concluded on July 22.

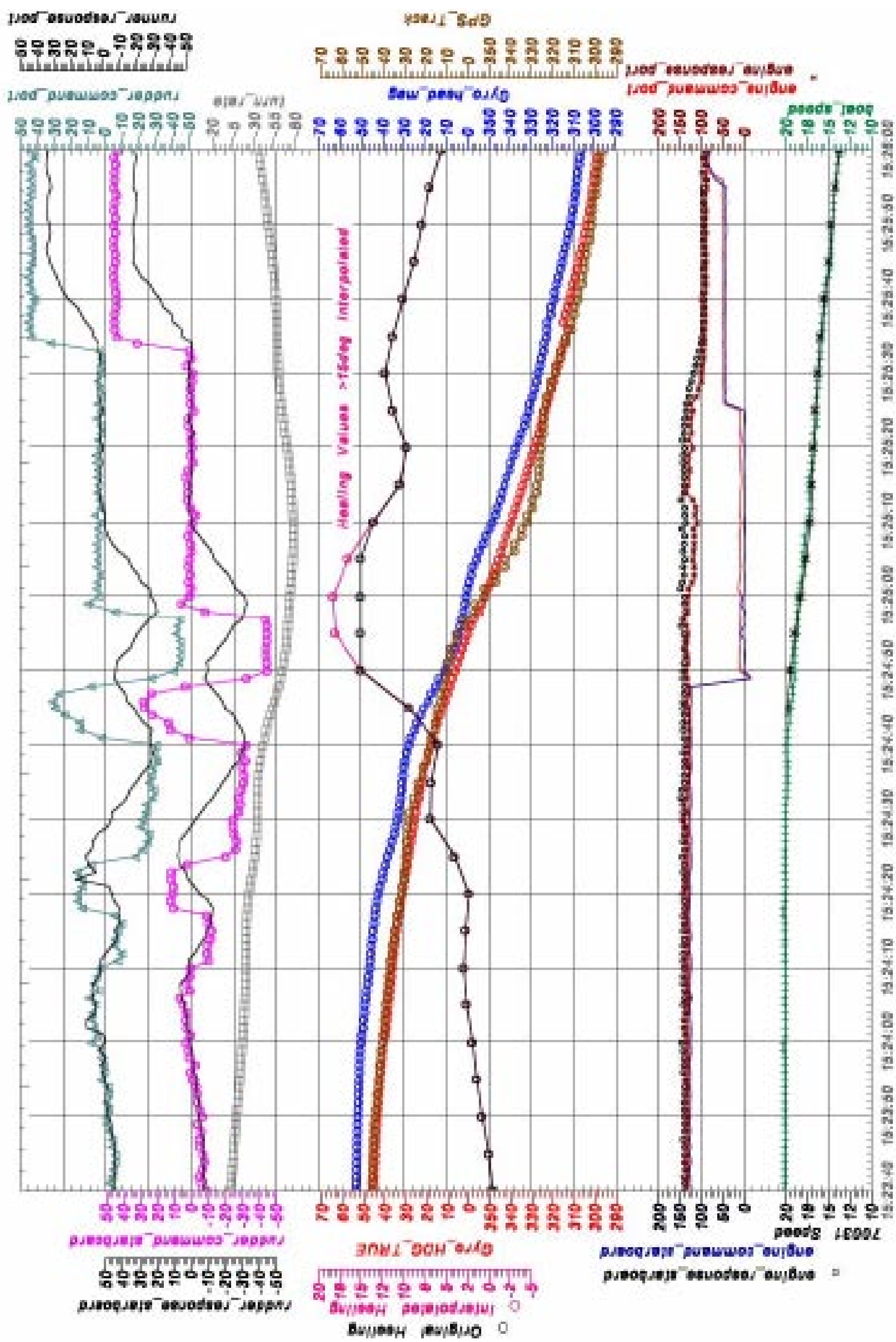
The Safety Board investigated the accident under the authority of the Independent Safety Board Act of 1974, according to the Board's rules. The parties to the investigation were the U.S. Coast Guard, Princess Cruises, and SAM Electronics.

Appendix B

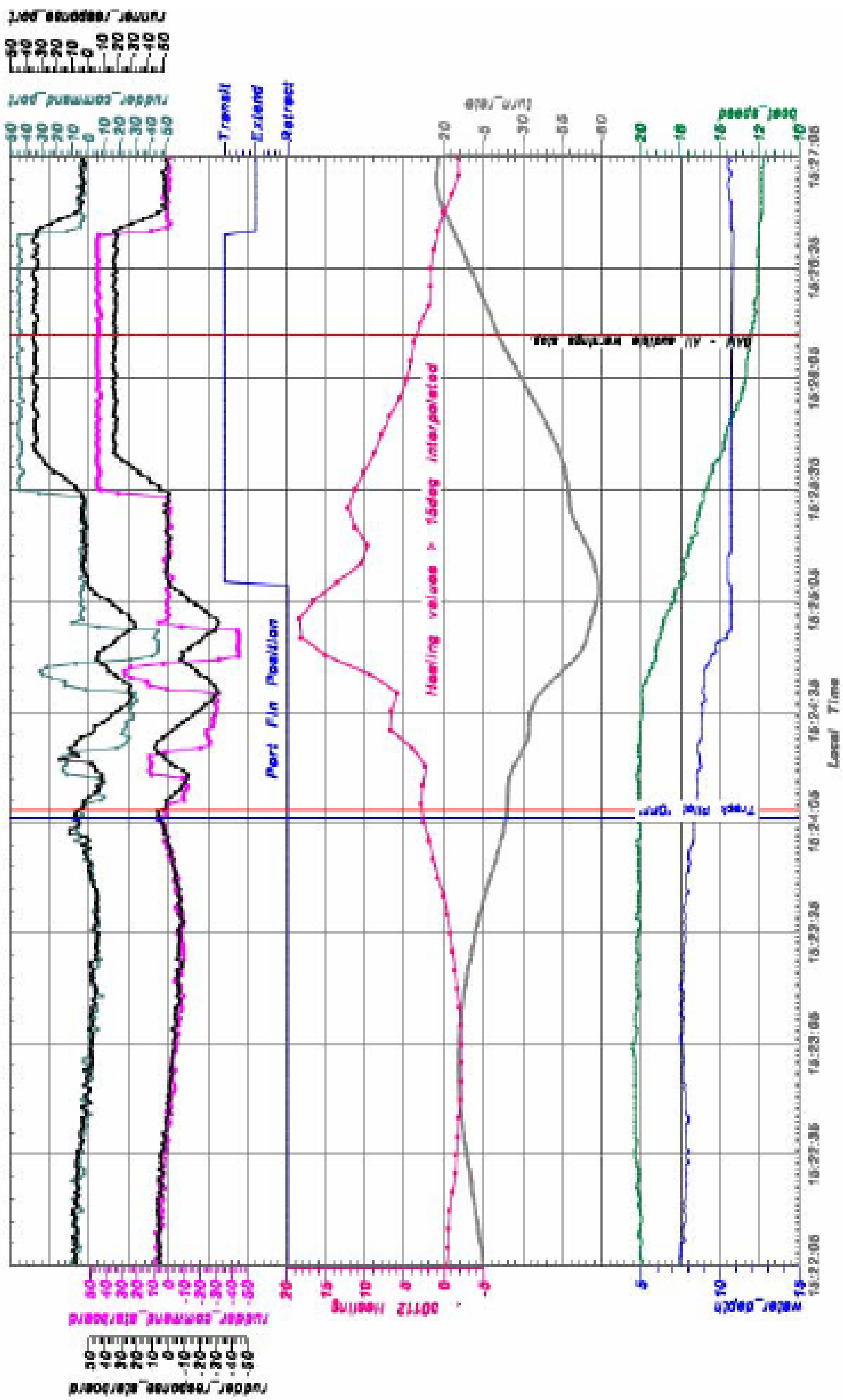
Voyage Data Recorder Data Plots


Princess Cruises Line, Crown Princess
Track Pilot "OFF"
Track Pilot "ON"
Track Pilot Alarm (Rudder Limit)
Track Pilot Alarm (Rudder Limit)
National Transportation Safety Board
Revised 28 March 2007
Local Time (Hrs:Min:Sec)

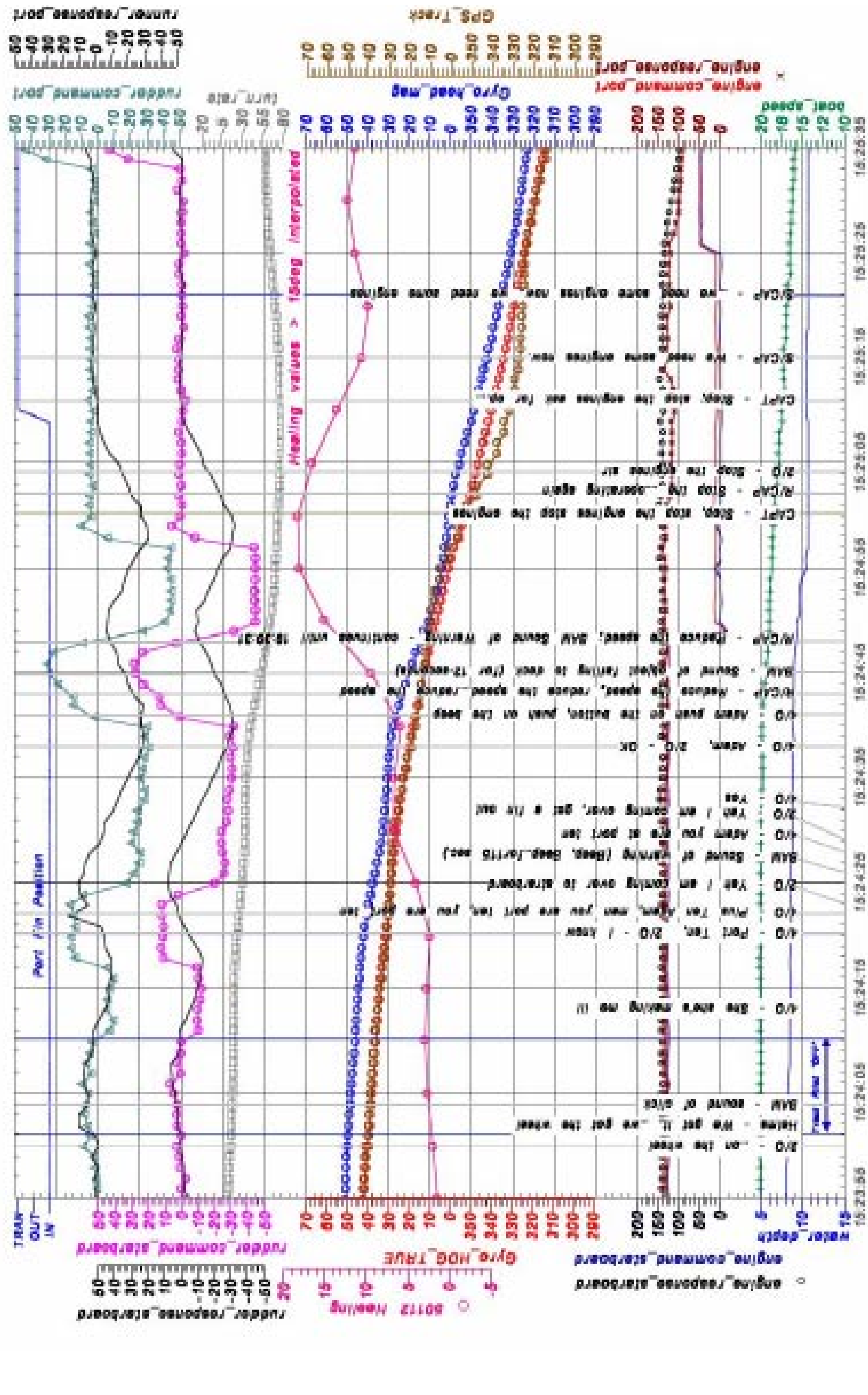
PLOT 1



PLOT 2


Port Fin Position
Transit
Extend
Retract
Local Time
water_depth
rudder_command_starboard
rudder_response_starboard
rudder_command_port
runner_response_port

Plot 3



Plot 4

Appendix C

Voyage Data Recorder Audio Transcript

The reader of this report is cautioned that the transcription of a bridge voice recorder audio recording is not a precise science but is the best product possible from a Safety Board group investigative effort. The transcript or parts thereof, if taken out of context, could be misleading. The transcript should be viewed as an accident investigation tool to be used in conjunction with other evidence gathered during the investigation. Conclusions or interpretations should not be made using the transcript as the sole source of information.

Transcript of a Broadgate voyage data recorder installed on cruise ship *Crown Princess*, which was involved in a heeling indicant that resulted in 298 injuries shortly after departing Port Carnival on July 18, 2006.

BAM	Bridge area microphone voice or sound source
CAPT	Voice identified as the captain
2/O	Voice identified as the second officer
S/CAP	Voice identified as staff captain
S/CAP(T**)**	Voice identified as staff captain on telephone
4/O	Voice identified as 4th officer
REL CAP	Voice identified as relief captain
AB/HELM-1	Voice identified as able body helmsman
INTCOM	Intercom communication
INT COM (e)	Intercom from engineroom
Radar Video	VDR radar video image
*	Unintelligible word
#	Expletive
@	Nonpertinent word
( )	Questionable insertion
[ ]	Editorial insertion

Note 1: Times are expressed in eastern daylight time (EDT).

Note 2: Words shown with excess vowels, letters, or drawn out syllables are a phonetic representation of the words as spoken.

Note 3: A nonpertinent word, where noted, refers to a word not directly related to the operation, control, or condition of the vessel.

Local Time	VDR Time	Source	Content
14:44:31	18:49:08	**2/O**	Forty-five
		4/O	Forty-five
14:44:34	18:49:11	**S/CAP**	Did you ask the Captain?
14:44:36	18:49:13	**REL CAP**	I think we should pass this…
		????	I'm pretty sure...
14:44:39	18:49:16	**S/CAP**	No No .So it is a CF buoy
		2/O	It is
14:44:43	18:49:20	**S/CAP**	Ah Ok
14:44:44	18:49:21	**S/CAP**	So forty-five, round number
		2/O	Um full away at forty-five
14:44:53	18:49:30	**INT COM** (e)	Ok what's that sorry
		S/CAP	forty-five
		2/O	At forty-five
14:44:58	18:49:35	**INT COM** (e)	forty-five Louie
		????	Unintelligible
14:45:23	18:50:00	**S/CAP**	Nostromo all flags
		CAPT	definitely star...
		4/O	ninety RPM
		2/O	ninety RPM
		????	Right it's time to go
		????	…so actually
		CAPT	So what exactly is the weather?
		????	me ah…do ah ...
		CAPT	…web site…
		S/CAP (T)	so is the bow…. cleared for sea?
14:47:03	18:51:40	**S/CAP**	Ok

Local Time	VDR Time	Source	Content
14:47:05	18:51:42	**S/CAP**	Anchors secured eh
		2/O	Anchors secured yea got that.
14:47:40	18:52:17	**S/CAP**	…he is outside the…
14:47:42	18:52:19	**CAPT**	ninety-five
		2/O	ninety-five
14:47:44	18:52:21	**S/CAP**	It's just ah - a depression they call it tropical.
14:48:32	18:53:09	**CAPT**	one two nine
14:48:34	18:53:11	**AB/HELM**	one two nine
14:51:13	18:55:50	**ECR**	twenty two point two
14:51:15	18:55:52	**2/O**	twenty two point two, yea the captain will speak to the chief.
		ECR	Ok
14:51:19	18:55:56	2/O	That was it, and…
14:51:23	18:56:00	BRIDGE	Sound of Phone ring….
14:51:28	18:56:05	CAPT	Hello Captain…
14:51:35	18:56:12	CAPT	Hay Carlo, we want to go as fast as we can for the time being for the weather.
14:52:00	18:56:37	CAPT	Port three
14:52:02	18:56:39	AB/HELM	Port three
14:52:32	18:57:09	CAPT	five-degrees
14:52:34	18:57:11	AB/HELM	five-degrees
14:56:01	19:00:38	CAPT	one zero zero
14:56:03	19:00:40	AB/HELM	one zero zero
14:57:24	19:02:01	AB/HELM	Heading one zero zero sir.
14:57:27	19:02:04	CAPT	Ok
15:00:51	19:05:28	CAPT	three thirty NACOS-1
		2/O	right sir

Local Time	VDR Time	Source	Content
15:01:10	19:05:47	BAM	Sound of switch
15:01:15	19:05:52	2/O	NACOS-1
15:01:16	19:05:53	CAPT	NACOS-1
15:01:17	19:05:54	2/O	Engaged
15:01:18	19:05:55	AB/HELM	…NACOS….
15:01:19	19:05:56	2/O	Wait there a second.
15:01:28	19:06:05	2/O	ECR coming down to one set of steering motors now.
15:01:33	19:06:10	ECR	OK one steering motor.
15:01:37	19O6:14	2/O	Ok we will do one and three
15:01:41	19:06:18	ECR	You need to keep the watertight doors closed
		CAPT	Yes still…
15:01:45	19:06:22	2/O	Yes please we will keep them closed for the time being.
15:02:47	19:07:24	CAPT	Looks like a tour boat….fish watching.
15:02:54	19:07:31	????	….. turning
15:02:59	19:07:36	S/CAP	Fish watching…
15:03:00	19:07:37	CAPT	yea ok
15:03:01	19:07:38	????	Right Adam
15:03:02	19:07:39	2/O	Sir
15:03:03	19:07:40	CAPT	You go ahead come around. Come around here.
15:03:07	19:07:44	2/O	Alright.
		????	unintelligible
15:03:13	19:07:50	CAPT	Were over there because you won't put it in
15:03:17	19:07:54	CAPT	Otherwise …traffic see the buoy see the buoy
15:03:19	19:07:56	2/O	Sir
15:03:20	19:07:57	S/CAP	that's the buoy
15:03:21	19:07:58	CAPT	and it's being able to access.

Local Time	VDR Time	Source	Content
15:03:22	19:07:59	2/O	Speeding up to max on 6
15:03:49	19:08:26	S/CAP	What's the range to that vessel….
15:03:51	19:08:28	CAPT	I don't know what…..
15:03:53	19:08:30	CAPT	NACOS-one?
15:03:54	19:08:31	2/O	NACOS-one
15:03:56	19:08:33	CAPT	Reese?????
15:03:57	19:08:34	2/O	parameters….set-up
15:04:01	19:08:38	CAPT	Rudder group set up
15:04:03	19:08:40	CAPT	set at ten….Yea
15:04:07	19:08:44	CAPT	She's applying port helm
15:04:12	19:08:49	CAPT	and you can stop two pumps running… yes it's always a start
15:04:17	19:08:54	CAPT	Now she's coming back
15:04:27	19:09:04	CAPT	….what are you set?
15:04:37	19:09:14	CAPT	I think we're better off with…
15:04:46	19:09:23	BAM	beep beep
15:04:55	19:09:32	CAPT	alright we're in NACOS, heading mode
15:04:59	19:09:36	CAPT	zero nine nine
15:05:01	19:09:38	CAPT	now we're going to port…
15:05:04	19:09:41	CAPT	Steadying up
15:05:05	19:09:42	CAPT	OK
15:05:06	19:09:43	BAM	beep beep beep…. (TP rudder limit, identified from radar image)
15:05:08	19:09:45	2/O	Rudder limit alarm.
		????	unintelligible
15:05:19	19:09:56	CAPT	Hopeless
15:05:22	19:09:59	2/O	I don't think we're on….
15:05:26	19:10:03	????	alright

Local Time	VDR Time	Source	Content
15:05:31	19:10:08	BAM	sound of click
		????	unintelligible switches
15:05:32	19:10:09	BAM	sound of click
15:05:33	19:10:10	2/O	I don't see why it is
15:05:36	19:10:13	CAPT	Dominico
15:05:37	19:10:14	S/CAP	yes sir
15:05:38	19:10:15	CAPT	We're wandering all over the place…, we put her into NACOS-1
15:05:43	19:10:20	CAPT	There's nothing wrong with the steering pumps, the helm is responding.
15:05:53	19:10:30	BAM	sound of phone ring
		CAPT	something
15:05:58	19:10:35	S/CAP	lendis parma (phone answer)
15:06:00	19:10:37	S/CAP	Ok…
15:06:05	19:10:42	S/CAP	next course
15:06:06	19:10:43	BAM	click
15:06:07	19:10:44	S/CAP	you alright with that?
15:06:09	19:10:46	CAPT	At the moment she is not responding other than10 degrees at a time
15:06:13	19:10:50	S/CAP	we are out of its range…for sure.
15:06:16	19:10:53	CAPT	Ah ha
15:06:20	19:10:57	CAPT	take the helm Louie
15:06:22	19:10:59	????	say again
15:06:24	19:11:01	????	Ok
15:06:27	19:11:04	BAM	Arr Arr (warning) followed by and simultaneous with beep beep beep….
15:06:29	19:11:06	????	You recommend it

Local Time	VDR Time	Source	Content
15:06:30	19:11:07	????	well done…
15:06:47	19:11:24	BAM	click
15:07:07	19:11:44	Radar Video	Rudder limit changed from 5 to 10 degrees
15:07:20	19:11:57	CAPT	ten degrees port ….; If we can't steer a track (questionable text)
15:07:23	19:12:00	S/CAP	Eddy, ?????
15:07:34	19:12:11	S/CAP	I have just increased rudder and the course; gain; and now it is left.
15:07:42	19:12:19	S/CAP	Unintelligible - approaching
15:07:48	19:12:25	S/CAP	five
15:08:00	19:12:37	BAM	beep beep beep…(rudder limit alarm)
15:08:03	19:12:40	Radar Video	Alarm List – TP Rudder Limit
15:08:07	19:12:44	S/CAP	
15:08:09	19:12:46	CAPT	Yea
15:08:25	19:13:02	????	unintelligible
15:08:37	19:13:14	BAM	sound of alarm five-tones
15:09:28	19:14:05	????	unintelligible
15:09:35	19:14:12	CAPT	What
15:09:36	19:14:13	S/CAP	… there is a party with ah course limit…..
15:10:32	19:15:09	2/O	…Captain
15:10:34	19:15:11	S/CAP	..increase too much…, we're at maximum
15:10:38	19:15:15	CAPT	No idea but I don't want her to (turn and drift).
15:10:43	19:15:20	BAM	high pitch alarm
15:10:53	19:15:30	S/CAP	unintelligible (laugh)
15:11:04	19:15:41	2/O	alright hang on
15:11:08	19:15:45	BAM	(sound of click) followed by high pitch tone
15:11:18	19:15:55	S/CAP	unintelligible

Local Time	VDR Time	Source	Content
15:11:23	19:16:00	S/CAP	wait turn around .. we are just in the middle don't move it, so what am I management ….
15:11:46	19:16:23	CAPT	master…according to our officers…
15:11:48	19:16:25	S/CAP	(Italian) si,… to a one hundred-meters….OK. (consistent with phone conversation)
15:11:53	19:16:30	BAM	sound of phone hung-up.
15:11:59	19:16:36	S/CAP	Is it ok now?
15:12:00	19:16:37	CAPT	No, ah no because, it was up to ten (meters)four miles, We're bring it down to radius two.
15:12:23	19:17:00	CAPT	Is it alright
15:12:26	19:17:03	S/CAP	No no its better to do it by hand.
15:12:29	19:17:06	S/CAP	it's applies
15:12:33	19:17:10	CAPT	you just applied it
15:12:34	19:17:11	S/CAP	applied within this, every time you change it applied, where she is adapting at this point.
15:12:36	19:17:13	CAPT	yea yea.
15:12:39	19:17:16	S/CAP	….so if you give it a change like oh (ten or fifteen) degrees you will adapt to that 4-mile range. But if you keep changing one by one then (it never or the number) stops it needs to…
15:13:03	19:17:40	2/O	I can just look at it
15:13:06	19:17:43	S/CAP	Yea, actually when you (hold or alter) this switch, it will show you continuous curve to the next track. And may be its when….applies…(unintelligible - ends at 15:13:20)
15:13:10	19:17:47	2/O	unintelligible
15:13:12	19:17:49	BAM	Phone ringing
15:13:23	19:18:00	CAPT	Ok
15:13:39	19:18:16	CAPT	Ok…put in nine nine nine
15:13:41	19:18:18	S/CAP	(conversation in Italian – continues until 15:15:16)
15:14:33	19:19:10	CAPT	stay in that turn,…..Ok we'll run like that.

Local Time	VDR Time	Source	Content
15:14:42	19:19:19	CAPT	unintelligible
15:15:05	19:19:42	CAPT	Where is the track?
15:15:07	19:19:44	2/O	unintelligible
15:15:15	19:19:52	CAPT	the track
15:15:24	19:20:01	CAPT	What's the next track
15:15:30	19:20:07	4/O	zero eight
15:15:35	19:20:12	CAPT	How do you check it?
		CAPT	Did you check it?
15:15:38	19:20:15	CAPT	How do you check it?
15:15:41	19:20:18	CAPT	Maybe the navigator put in the wrong number.
15:15:48	19:20:25	CAPT	….. we better check it.
15:15:50	19:20:27	S/CAP	We can catch the liar
15:15:55	19:20:32	CAPT	No, that's only if you…
15:16:11	19:20:48	S/CAP	That number can not be dialed, there is ah another one that can be I want him, I want him to dial another one, larger that I can see from here.
		CAPT	Oh yea yea.
15:16:20	19:20:57	S/CAP	logically I can see from here not that I could put that .. but that number is on the first leg on the track line so that's come from..
15:16:33	19:21:10	CAPT	still good to check
15:16:36	19:21:13	S/CAP	still good to check. Put the EBL on and ah.
15:16:38	19:21:15	CAPT	That's Ok;
15:16:39	19:21:16	S/CAP	This is reversed.
15:16:40	19:21:17	CAPT	I' am going to leave on "O" 4, {then, check please check back.} are you happy?
15:16:44	19:21:21	2/O	I am sir
15:16:45	19:21:22	CAPT	Check each …zero four zero..{unidentified background conversation}

Local Time	VDR Time	Source	Content
15:16:55	19:21:32	2/O	Can not.
15:16:56	19:21:33	CAPT	Alright
15:16:57	19:21:34	S/CAP	Had a job for the gadget.
15:16:59	19:21:36	CAPT	I don't know how long {he's been with it}
15:17:01	19:21:38	2/O	nine seven zero ..You guessed it…
15:17:03	19:21:40	S/CAP	One hundred percent
15:17:04	19:21:41	CAPT	Yes
15:17:05	19:21:42	2/O	Check
15:17:06	19:21:43	REL/CAP	We were we have some office books booklets which are in an envelope… we have some big big books so many books…[continued background conversation until 19:22:58]
15:17:13	19:21:50	CAPT	Anchors secured for…
15:17:14	19:21:51	BAM	Sound of two sharp bangs followed by two beeps.
15:17:15	19:21:52	CAPT	the doors ….one hundred and thirty….
15:17:18	19:21:55	2/O	Sixtieth
15:17:20	19:21:57	S/CAP	It is nine o'clock…quarter past eleven..
15:17:23	19:22:00	2/O	and the depth?
15:17:23	19:22:00	S/CAP	[background conversation (lottery betting etc.) continues until19:22:59]
15:17:28	19:22:05	CAPT	Ahm…just before they open…. you have the starboard side?
15:17:40	19:22:17	CAPT	You happy with the books, the staff captain books?……
15:17:41	19:22:18	2/O	yes sir
15:17:43	19:22:20	????	You know…
15:17:46	19:22:23	CAPT	It's only going to be a few minutes…and
		2/O	I know
		????	Unintelligible
15:18:02	19:22:39	????	It's not that at all

Local Time	VDR Time	Source	Content
15:18:04	19:22:41	S/CAP	You'll have to check with your Bosun.
		????	What's the …?
15:18:08	19:22:45	????	I'm trying to get near…
15:18:09	19:22:46	????	Remember you can use that without bringing it up
15:18:12	19:22:49	2/O	Yea
15:18:14	19:22:51	CAPT	Ok you got the conn.
15:18:16	19:22:53	2/O	I have the conn.
15:18:18	19:22:55	2/O	Luigi….
15:18:20	19:22:57	4/O	Yes sir
15:18:32	19:23:09	S/CAP	We have also got four charts from the area, so that ah we will also have paper charts for the gadget.
15:18:39	19:23:16	????	For what?
15:18:39	19:23:16	CAPT	The wind sensors slipped has it?
15:18:41	19:23:18	????	Ah this….
15:18:43	19:23:20	CAPT	starboard wing
15:18:44	19:23:21	2/O	…could be arriving in
15:18:45	19:23:22	S/CAP	New York
15:18:46	19:23:23	S/CAP	So that Luigi can check in the track on the chart; which one, check the track no put ah..
15:18:51	19:23:28	REL/CAP	Which one is the pilot..?
15:18:57	19:23:34	CAPT	Yea we have the wind beside us.
15:18:58	19:23:35	????	You said that..
15:19:10	19:23:47	????	Ah ______watch
15:19:14	19:23:51	CAPT	I think I will go and put my feet up.
15:19:18	19:23:55	????	Feet up Feet up
15:19:20	19:23:57	S/CAP	Yeah…. I was thinking the same, but ah I can't do it too late now, too late.

Local Time	VDR Time	Source	Content
15:19:28	19:24:05	S/CAP	Ah, I'll see you later minute second second ……. here.
15:19:34	19:24:11	S/CAP	The chief is doing ah, oh ah he has to change a couple of things and one operator…. that's fine.
15:19:42	19:24:19	S/CAP	
15:19:47	19:24:24	CAPT	…I would like to walk through another..
15:19:50	19:24:27	S/CAP	No No not for this ship no….
15:19:54	19:24:31	S/CAP	(unintelligible conversation)
15:20:17	19:24:54	????	….captain
15:20:23	19:25:00	CAPT	Pick it up
15:20:24	19:25:01	CAPT	Adam
15:20:28	19:25:05	CAPT	It's all happening Adam this is the Captains handing over
15:20:31	19:25:08	2/O	And…
15:20:56	19:25:33	2/O	I printed it out… (unintelligible conversation)
15:21:08	19:25:45	2/O	…I just wanted to double check
15:21:10	19:25:47	S/CAP	Ah you want to check mine against yours?
15:21:12	19:25:49	2/O	yeah
15:21:24	19:26:01	CAPT	…safety..
15:21:26	19:26:03	S/CAP	I am still available to go through that with you check.
15:22:02	19:26:39	S/CAP	Ok Nico I'll see you later I am going to …office.
15:22:09	19:26:46	REL/CAP	….chart.
15:22:11	19:26:48	2/O	sorry
15:22:11	19:26:48	2/O	No but from New York we'll have the charts from New York
15:22:21	19:26:58	REL/CAP	We don't have any charts here, we don't have any charts from here to New York
15:22:26	19:27:03	2/O	We do but just for the cadets for training purposes, we've ordered a few extra charts so they can do some practicing, ah when we arrive in New York

Local Time	VDR Time	Source	Content
15:22:37	19:27:14	REL/CAP	Anyway next time we use the parallel index, we go with the parallel indexing and you see how much …..
15:22:44	19:27:21	????	I use the (questionable text) one here….
15:22:50	19:27:27	REL/CAP	Ah the line
15:23:11	19:27:48	4/O	You are still ah, you are still ah, turning
15:23:14	19:27:51	2/O	Sorry
15:23:11	19:27:48	4/O	You are still turning
15:23:17	19:27:54	2/O	Na na, it's a, well a few degrees at a time Luigi not much.
15:23:24	19:28:01	REL/CAP	Anyway Adam ….
15:23:28	19:28:05	2/O	Alright
15:23:31	19:28:08	REL/CAP	I want this because I detected something….
15:24:00	19:28:37	2/O	….on the wheel
15:24:02	19:28:39	Helm	We got it, we got the wheel
15:24:05	19:28:42	BAM	sound of click
15:24:13	19:28:50	4/O	She She's making me ill
	.		
15:24:20	19:28:57	4/O	port ten
15:24:21	19:28:58	2/O	I know
15:24:22	19:28:59	4/O	Port ten Adam, man you are port ten, you are port ten…
15:24:23	19:29:00	2/O	Yah I am coming over to starboard
15:24:26	19:29:03	BAM	Sound of warning (Beep, Beep continues until 19:30:52)
15:24:28	19:29:05	4/O	Adam you are at port ten
15:24:29	19:29:06	2/O	Yah I am coming over; get a fin out
15:24:32	19:29:09	4/O	Yes
15:24:36	19:29:13	BAM	Additional warning sounds for less than second.
15:24:38	19:29:15	4/O	Adam
15:24:39	19:29:16	2/O	OK
15:24:41	19:29:18	4/O	Adam push on the button, push on the beep

Local Time	VDR Time	Source	Content
15:24:43	19:29:20	REL/CAP	Reduce the speed, reduce the speed, reduce the speed
15:24:45	19:29:22	BAM	Sound of objects falling to deck. (continues until 19:29: 39)
15:24:46	19:29:23	????	unintelligible (sorry)?????…..
15:24:47	19:29:24	BAM	Sound similar to door opening.
15:24:48	19:29:25	REL/CAP	Reduce the speed.
15:24:48	19:29:25	BAM	Sound of warning, (continues until 19:30:31)
15:25:00	19:29:37	CAPT	Stop the engines Stop the engines
15:25:02	19:29:39	REL/CAP	Stop the…..operating again
15:25:04	19:29:41	2/O	Stop the engines sir
15:25:11	19:29:48	CAPT	Stop; stop the engines ask for op…
		????	unintelligible
15:25:15	19:29:52	S/CAP	…we need some engines now.
15:25:16	19:29:53	CAPT	…we need to inspect the tanks…
15:25:21	19:29:58	S/CAP	we need some engines now; we need some engines
15:25:26	19:30:03	BAM	Sound of tones that precede Public Address System announcement.
15:25:33	19:30:10	CAPT	….sit-down where you are ……there is a problem with the steering gear and we are bring the ship back….
15:26:06	19:30:43	2/O	…fuse boxes check on all the fuse buttons
15:26:11	19:30:48	????	starboard.
15:26:12	19:30:49	S/CAP	Keep her to starboard
15:26:15	19:30:52	BAM	All audible warnings stop.
15:26:20	19:30:57	????	What time is it?
15:26:21	19:30:58	CAPT	Alright every body get round quickly, see what has happened, there must be some people hurt, call the ah surgery, …call the surgery.

Appendix D

Pertinent Regulations and Guidelines

When the *Crown Princess* entered service, the following regulations and guidelines pertained to the NACOS system:

- International Electrotechnical Commission standard 62065 (2002), "Maritime navigation and radiocommunication equipment and systems—Track control systems—Operational and performance requirements, methods of testing and required test results."
- International Maritime Organization Maritime Safety Committee (MSC) resolution 74 (69), May 12, 1998. Adoption of new and amended performance standards [regarding GPS/GLONASS receivers, track control systems, AISs, and echo-sounding equipment].
- International Electrotechnical Commission standard 61174 (2001). "Maritime navigation and radiocommunication equipment and systems—electronic chart display and information system (ECDIS)—operational and performance requirements, methods of testing and required test results."
- International Convention for Safety of Life at Sea (SOLAS) chapter V, regulation 15, "Principles relating to bridge design, design and arrangement of navigational systems and equipment and bridge procedures."
- International Maritime Organization MSC circular 1061, issued January 6, 2003, "Guidance for the operational use of integrated bridge systems."

Since the vessel entered service, the International Maritime Organization has taken actions pertinent to the INS system on the *Crown Princess*. These include:

- International Maritime Organization MSC 82/WP.8, issued December 8, 2006, "Draft report of the Maritime Safety Committee on its Eighty-second Session."
- Standards of Training and Watchkeeping (STW) 38/17, issued February 8, 2007, "Report to the Maritime Safety Committee."

International Electrotechnical Commission standard 62065 established performance standards for an autopilot system that steers a vessel along a predetermined track. At the time the NACOS 65 was developed, the International Electrotechnical Commission had not yet developed INS standards. As a result, the NACOS system on the *Crown Princess* met the trackpilot standards of International Electrotechnical Commission standard 62065, the pertinent standards of MSC 74(69), and classification society approval for an INS but not International Electrotechnical Commission standards for an INS. In 2006, the International Electrotechnical Commission adopted standard 6192, which established operational and performance standards for INSs. SAM Electronics told the Safety Board that the next NACOS generation INS will meet the operational and performance criteria of International Electrotechnical Commission standard 61924.

SOLAS chapter V, regulation 15, provides the basic foundation for the design and arrangement of navigational systems, so that they enhance the performance of deck watchkeepers and bridge crewmembers.

MSC circular 1061 calls for companies to incorporate their policies on the use of automation and the INS in their vessel operating manuals. The circular also addresses training in INS use, stating that companies, “in cooperation with the relevant manufacturers, should establish a training programme for all officers which have operational duties involving the INS.”

MSC 82, the 82nd meeting of the MSC, produced several working papers and suggestions for action. Its human element working group recommended that the International Maritime Organization include ergonomic criteria in the application of SOLAS regulations to INSs and in training related to INS use.

The report of the full MSC includes information regarding British research that had been “aimed at developing guidance for the mitigation of human error in automated shipborne maritime systems.” As the report noted:

> The research had identified a range of problems which could result from inappropriate or incorrect specification, design, selection, installation and use of automated systems, and suggested some methods of mitigation. In their opinion, the findings of this research should be considered by designers, shipbuilders, trainers, shore-based company management, ship-based management and seafarers themselves, to assist in the safe, effective and efficient use of automation aboard ships. (82/15.14)

In addition, in 2006 the MSC instructed its STW subcommittee to review the International Convention on Standards of Training, Certification, and Watchkeeping for Seafarers (STCW code). In 2007, the MSC specified that such a review should include an issue involving the understanding of “automatic systems through familiarization training. . . .” Specifically, the subcommittee reported to the MSC that it:

Identified that training recommendations given by performance management guidelines such as Integrated Navigation Systems, Integrated Bridge Systems and Bridge and Engine-room Resource Management, should be included within the STCW Convention with a view to seafarers understanding the limitations and weaknesses of automated systems and instructed STW 38 to consider this under its existing agenda item, "Compressive Review of the STCW Convention and the STCW Code."[1]

[1] STW 38/17, February 8, 2007, "Report to the Maritime Safety Committee," p. 31.

Appendix E

Model Curriculum Proposed by International Maritime Organization

The suggested curriculum on IBS/INS system use developed by the International Maritime Organization assumes that the student has knowledge of deck operations and navigation but no IBS/INS experience. The model course is intended to serve as a guide for member states that are developing or certifying IBS/INS systems. States may use the curriculum, but the International Maritime Organization does not mandate such a course and does not specify when a mariner should take it, or the length of time that can elapse between when someone has completed the course and when that person uses an INS in actual vessel operations. The general objective of the course is noted in the Standards on Training and Watchkeeping (STW) circular, as follows:

> The safe and efficient use at sea of IBS and INS requires a level of knowledge beyond that normally given in the training of an officer in charge of a navigational watch. It is not just a matter of learning to use new controls, display techniques or how to switch on and off automatic functions. More importantly, it is learning the decision making process that must be applied in order [to] gain the full benefits of the integration in a safe manner and avoid the new problems that automatic controls and integrated systems can sometimes provide (p. 4).

The STW circular includes a detailed instructor's guide, a teaching syllabus, guidance on specific subject areas, recommendations both paper-and-pencil and simulator-based student exercises to demonstrate competence in the material, and guidance for evaluating a student's knowledge of the material at the completion of the training.

In addition to developing the model course, the International Maritime Organization's STW subcommittee, at its 37th session (STW 37) in 2006, considered the need for a comprehensive review of the STCW convention and the STCW code, and proposed a work item with a target completion date of 2008. In May 2006, the Maritime Safety Committee (MSC 81)[1] endorsed the proposal of STW 37 and included in the provisional agenda for STW 38 a high priority item on "Comprehensive Review of the STCW Convention and the STCW Code," with a target completion date of 2008. At the subsequent meeting of the MSC, a resolution was passed instructing STW 38 to consider addressing the issue of human error in operator interactions with integrated bridge systems and the need for "basic

[1] Report of the Maritime Safety Committee 81st session, MSC/81/25, paragraph 23.57.2.

education and familiarization training of seafarers" as an agenda item in its "Comprehensive Review of the STCW Convention and the STCW Code".[2]

The following pages reproduce the detailed teaching syllabus from the model IBS/INS course developed by the International Maritime Organization's subcommittee on standards of training and watchkeeping. In addition to outlining the contents of the curriculum, the syllabus contains references to relevant publications and to teaching aids.

[2] Report of the Maritime Safety Committee, MSC 82/24, paragraph 15.50

Part C: Detailed Teaching Syllabus

The detailed teaching syllabus indicates the contents of the course and appropriate references and teaching aids.

- **Learning objectives**

The detailed teaching syllabus has been written in learning objective format in which the objective describes what the trainee must do to demonstrate that knowledge has been transferred. This format is an appropriate teaching and assessment tool to express:

- The depth of understanding of a subject and the degree of familiarization with a subject on the part of the trainee
- What capabilities the trainee should really have and be able to demonstrate

Every instructor is encouraged to teach learning in an 'objective-related' way instead 'material-related'. In this context, all objectives are understood to be prefixed by the words, 'The expected learning outcome is that the trainee is able to . . . '.

To indicate the degree of learning outcome of this course, the learning objectives for the Detailed Teaching Syllabus can be classified in three 'dimensions':

- C (cognitive)
- A (affective)
- P (psycho-motoric)

Within a dimension, they are hierarchised by increasing complexity (C1 to C6, A1 to A5, and P1 to P5) where the complexity (depth, familiarization) is expressed (following B. Bloom and others) by a typical verb as follows:

Cognitive dimension of learning objectives

C1	Knowledge	describe, outline
C2	Comprehension	explain
C3	Application	apply, perform, operate
C4	Analysis	analyse
C5	Synthesis	synthesise, construct, plan
C6	Evaluation	assess

Affective dimension of learning objectives

A1	Reception; notice	recognize
A2	Response	respond
A3	Value	value
A4	Organisation	organise
A5	Value characterisation	accept, appreciate

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Psycho-motoric dimension of learning objectives

P1	Imitation	imitate
P2	Manipulation	manipulate
P3	Precision	move, mark
P4	Coordination	co-ordinate (operations, menus)
P5	Naturalisation	automate, interiorate

- **References and teaching aids**

In order to assist the instructor, references are shown against the learning objective to indicate IMO references and publications, bibliographies, textbooks and other references, as well as additional teaching aids which the instructor may wish to use when preparing course material. The material is listed in the course framework. The following notations and abbreviations are used:

R	IMO reference
T	Text book and other references
B	Bibliography
A	Teaching aid
Ap.	Appendix
Ch.	Chapter
p.	Page
Para.	Paragraph
Sc.	Section

The following are examples of the use of references:

"R3 Para.3.1", refers to paragraph 3.1 of MSC Circular 1061;
"A1 Para.D5.4", refers to paragraph 5.4 in Part D of this manual;
"A1 Sc.DSim", refers to the Simulator Exercises section in Part D of this manual.

- **Instructor Manual**

The Instructor Manual (Part D) is included to provide additional information to instructors. It is designed to help further in structuring and organising a specific course. At the time of compilation of this model course there were no known text books covering the subject material. For this reason Part D includes extra information on the subject. The instructor is recommended to gain additional technical material from IBS and INS suppliers. Suppliers of simulators are also good sources of technical information.

The instructor should take pains to present the material within 'a-use-at-sea' context. It is not just a matter of imparting technical knowledge. In order to do this the instructor needs to extrapolate his or her seagoing experience (which is unlikely to have covered IBS and INS) to incorporate the ideas and disciplines of using an IBS/INS.

- **Detailed Teaching Syllabus**

All objectives are understood to be prefixed by the words "The expected learning outcome is that the trainee is able to …". The Teaching Aid reference to A1 Sc.DSim, refers to the section on Simulator Exercises in Part D of this model course.

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Learning objectives		IMO Reference	Biblio-graphy	Teaching Aid
1	**Definitions of IBS and INS**			
	Section objective: to understand the basic concepts of the terms IBS and INS and that IMO have specific definitions of what constitutes an IBS and an INS			
1.1	Explain the terms IBS and INS	R1 Para.1, R2 Para. 1		A1 Para.D1, A2, A3
1.2	Recognize and accept the IMO performance standards for IBS	R1		A1 Para.D1
1.3	Recognize and accept the IMO performance standards for INS	R2		A1 Para.D1
1.4	Recognize and accept the IMO guidance for the use of IBS. On completion of course to be able to outline these guidelines.	R3		A1 Para.D1
1.5	Explain that systems referred to as IBS or INS on a particular vessel may not conform to the requirements of IMO detailed in 1.2 and 1.3 above			A1 Para.D1
2	**Benefits of integration**			
	Section objectives: to understand the benefits of using IBS and to comprehend the main terms used in describing their use			
2.1	Describe the meaning of human machine interface (HMI), work station, failure analysis			A1 Para.D2.1
2.2	Outline the broad benefits of using IBS, including common HMI, improved situational awareness, harmonised alarms, increased automation, fail-to-safe functionality and possible use of common workstations	R8 Ch.V Reg.15		A1 Para.D2.2
2.3	Outline potential functions that may be incorporated into an IBS	R1 Para.2		A1 Para.D2.3
3	**Bridge procedures**			
	Section objectives: to understand the need to operate to bridge procedures, what these procedures should include and where the procedures should be found			

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Learning objectives		IMO Reference	Biblio-graphy	Teaching Aid
3.1	Explain and accept the need and use of written bridge procedures for the operation of an IBS and that these help to ensure optimum workload management	R3 Para.3		A1 Para.D3
3.2	Explain what should be in the procedures and that they are contained within the Vessel Operating Manual or an equivalent manual	R3 Para.3.1		A1 Para.D3
4	**Principles of use of IBS** ***Section objectives: to understand the basic principles of using an IBS***			
4.1	Explain the term *multifunction display and controls*	R2 Para.3.5		A1 Para.D4.1
4.1.1	Explain the benefits of multifunction displays and controls			A1 Para.D4.1
4.1.2	Explain and operate the principal HMI technology used on multifunction displays and workstations: o Use of keyboards, mouse, tracker ball, menus and touch screens to access and input data o Switch between functions and recognize the current function o Simultaneously display and operate two or more functions on the same screen, (use of Windows).			A1 Para.D4.1, A4
4.1.3	Explain the dangers of viruses and accessing unauthorised areas in the IBS software			A1 Para.D4.1, A4
4.2	Explain the terms *integrity* (of data), data latency and data validity	R1 Para.3.3.3, R2 Para.4.1.10, R9		A1 Para.D4.2
4.2.1	Assess data that is suitable, doubtful or unsuitable for use			A1 Para.D4.2, A4

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Learning objectives		IMO Reference	Biblio-graphy	Teaching Aid
4.3	Explain and accept the importance of mode awareness within the total concept of situational awareness	R3 Para.2.1		A1 Para.4.3
4.3.1	Demonstrate mode awareness on a multifunction display			A1 Para.D4.3, A1 Sc.DSim
4.4	Explain what is meant by the term *failure analysis.*	R3 Para.2.3		A1 Para.D4.4
4.4.1	Explain that all IBS and INS installations have had a failure analysis process documented and that this documentation will have been used in developing the relevant parts of the VOM.	R1 Para.3.4, R2 Para.6.2, R3 Para.2.3		A1 Para.D4.4
4.5	Explain the types of alarms, (warnings) and indicators	R10 Para.2-6,		A1 Para.D4.5
4.5.1	Recognize and accept the IMO Code on Alarms and Indicators	R10		A1 Para.D4.5
4.5.2	Recognize functional groups and alarm management priority	R1 Para.5.2, R2 Para. 4.3		A1 Para.D4.5, A1 Sc.DSim, A4
4.5.3	Explain alarm acknowledgement and the need to take appropriate action			A1 Para.D4.5, A1 Sc.DSim, A4, A5
4.5.4	Explain 'back-up officer' alarm			A1 Para.D4.5
4.6	Explain and accept that procedures will need to be understood for normal operation of the IBS and for emergency and abnormal conditions	R3 Para.3.2,3.3		A1 Para.4.6
4.6.1	Recognize procedures from a VOM and respond to them appropriately when performing example tasks in normal, abnormal and emergency conditions	R3 Para.3		A1 Para.4.6, A1 Sc.DSim, A4, A5

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	Learning objectives	IMO Reference	Biblio-graphy	Teaching Aid
4.7	Explain that an IBS may be capable of keeping automated records.	R3 Para.3.5, R7		A1 Para.4.7
4.7.1	Recognize automated record procedures from a VOM and operate an IBS simulator to mark, start, end and store them	R3 Para.3.1,3.5		A1 Para.4.7, A1 Sc.DSim, A4
4.8	Explain that when an IBS is modified or receives a new software version there should be a period of functional testing and that other cautions need to be observed	R3 Para.4		A1 Para.4.8
4.8.1	Recognize and respond appropriately to example limited functionality instructions when using an IBS simulator			A1 Para.4.8, A1 Sc.DSim, A4, A5
4.9	Explain appropriate decision making processes when using an IBS that will lead to good seamanship		B1	A1 Para.4.9, A1 Sc.DSim, A4, A5
4.9.1	Explain the dangers inherent in the undisciplined use of an IBS			A1 Para.4.9
5	**Principles of use of INS**			
	Section objectives: to understand the basic principles of using an INS			
5.1	Explain the purpose of an INS	R2 Para.1		A1 Para.D5.1
5.1.1	Describe the three categories of INS defined by IMO	R2 Para.2.3		A1 Para.D5.1
5.2	Explain the term *sensor*	R2 Para.3.6		A1 Para.D5.2
5.2.1	Explain the terms *primary* and *secondary*, when applied to sensors on an IBS		B4	A1 Para.D5.2
5.3	Explain the term *integrity monitoring* when applied to navigation systems	R2 Para.4.1.10, 4.1.11		A1 Para.D5.3
5.3.1	Explain the terms: *plausibility checks*, *validity checks*, *integrity checks*		B4	A1 Para.D5.3
5.3.2	Explain Receiver Autonomous Integrity Monitoring (RAIM), as used in GNSS		B2	A1 Para.D5.3

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Learning objectives		IMO Reference	Biblio-graphy	Teaching Aid
5.3.3	Assess and respond appropriately to navigation sensor data that is suitable, doubtful or unsuitable for use			A1 Para.D5.3, A1 Sc.DSim, A4
5.4	Explain the terms *consistent common reference system* and *consistent common reference point*	R2 Para.3.2	B4	A1 Para.D5.4
5.4.1	Perform handling of a vessel in a scenario necessitating a change in consistent common reference point			A1 Para.D5.4, A1 Sc.DSim, A4, A5
5.5	Explain that exchange of data between the elements of an INS conforms to rules laid down in IEC 61162.	R2 Para.4.1.12	B3	A1 Para.5.5
5.5.1	Outline the structure of a message taken from IEC 61162		B3	A1 Para.5.5
5.6	Explain the three categories of INS, defined as INS(A), (B) and (C), also explain that many ships have integrated navigational functionality that do not necessarily conform with these categories	R2 Para.2.3		A1 Para.5.6
5.6.1	Assess whether a particular INS configuration is an INS(A), (B) or (C) or does not meet any of these categories			A1 Para.D5.6, A1 Sc.DSim, A4
5.7	Explain the fail safe features of an INS(A), (B), and (C)	R2 Para. 4.3, 6	B4	A1 Para.5.7
5.8	Explain the use of manual checking of navigational integrity, including use of radar and ECDIS functions to assist this			A1 Para.D5.8, A1 Sc.DSim, A4, A5
5.9	Explain the Organizations recommendations on terms, abbreviations and symbology	R11, R12		A1 Para.5.9
6	**Automatic control functions of an INS(C)** ***Section objectives: to understand the basic principles of using the automatic control functions of an INS***			

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Learning objectives		IMO Reference	Biblio-graphy	Teaching Aid
6.1	Describe the basic functionality of INS(C) automatic control	R4 Para.5		A1 para.6.1
6.2	Explain the benefits and cautions of using automatic control functions	R3 Para.3		A1 Para.D6.2, A1 Sc.DSim, A4, A5
6.3	Describe the functionality of a track controller. (Note that heading controllers - automatic pilots - are covered in Model Course 7.03)	R4 Para.5		A Para.6.3
6.4	Explain the operation of a track controller at sea	R4		A1 Para.D6.4,
6.4.1	Operate a track controller in a simulated environment, responding correctly to normal. abnormal and emergency conditions	R4, R13		A1 Para.D6.4, A1 Sc.DSim, A4, A5,
7.	**Familiarization training** ***Section objective: to understand the training responsibilities in the use of IBS and INS equipment and the information that needs to be given and assimilated in order to operate a specific IBS or INS***			
7.1	Accept and explain the requirements of STCW and the ISM code concerning training and familiarization	R5, R6		A1 Para.D7
7.2	Explain the various methods of acceptable familiarization training for IBS or INS			A1 Para.D7
7.3	Explain that there are guidelines for manufacturers and Companies on familiarization training for IBS			A1 Para.D7
7.4	Explain the contents of the recommended familiarization training checklist			A1 Para.D7, A1 App.

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Appendix F

International Maritime Organization Guidance on Integrated Navigation System Training

Appendix 2 – Guidance to equipment manufacturers for the provision of on-board familiarization material

1 General

1.1 It is a requirement of the International Safety Management Code (ISM) that personnel working on assignments related to safety and the protection of the environment need to be given proper familiarization with their duties.

1.2 To assist with this process it is required that the INS equipment manufacturer or system integrator provides suitable training material that may be used by the ship operator as a basis for onboard familiarization of users.

1.3 The material is intended to be used by bridge officers who have had generic training in the use of INS through attending shore-based instruction based on the Organization's Model Course 1.32 "Operational use of Integrated Bridge Systems including Integrated Navigation Systems".

1.4 The intention of the familiarization material is that it should give a rapid means of understanding the configuration of the INS and its method of operation. General concepts concerning the use of INS are not required to be part of the material, as these would unnecessarily increase the duration of the familiarization training.

1.5 The material should be organized such that it represents the actual equipment and configuration that is fitted to the ship.

2 On-board familiarization training for INS

2.1 The aim of familiarization training is to explain the configuration, functions, limitations, controls, displays, alerts and indications of the specifically installed INS.

2.2 It should allow an OOW, unfamiliar with the ship's equipment but trained in the generic use of INS, to become rapidly acquainted with the installed system.

2.3 Emphasis should be given on producing effective familiarization training that can be completed in the shortest possible time. This will help maximize the probability that the process will be properly completed.

2.4 For a typical system it may be expected that it will take no longer than 30 minutes for a qualified user to undertake INS familiarization training. This time does not include the time taken to become familiar with major interconnected functionality, such as radar and ECDIS.

2.5 Familiarization can take a number of forms. The following are illustrative examples but other effective methods of training are acceptable:

- computer-based training on the vessel. Such training may also be appropriate to be used remotely (e.g. on a notebook computer of a new user, prior to joining the ship)
- a training mode on the fitted INS

- a training video (on tape, disk or solid state memory), supported by a self-training manual
- a stand-alone self-training manual.

2.6 The topics that need to be covered are listed in section 3 below.

2.7 The functions of the INS should be broken down into logical top-down descriptions.

2.8 The familiarization material does not replace the User Instruction Manual. Appropriate references can be made to it from within the material. This may be beneficial when describing more detailed operations or to reference large diagrams.

2.9 For lesser used, non-critical functions it is only necessary to reference the relevant section in the User Instruction Manual, rather than them having to be included in their entirety in the familiarization material. Ideally, material is provided for such functions but with instructions to enable the user to skip these sections, as appropriate, until a more convenient opportunity.

2.10 Familiarization is best given within the context of the vessel's normal bridge operating procedures. These procedures are normally contained within the Vessel Operating Manual or equivalent document.

3 Familiarization training framework

3.1 General description

3.1.1 This should start with a top-level functionality description including the identification of the types of automatic control that are provided (if any).

3.1.2 A description should be given of the connected equipment that forms the INS, to a level that a normal user would require for operation (not maintenance). This description could be in the form of a block diagram.

3.1.3 The general philosophy of operation should be explained, including a description of the human machine interfaces. If automatic modes of operation are provided a general description of these is also required.

3.1.4 The physical location of all workstations and other displays and controls should be identified.

3.1.5 A description of the CCRS and identification of the CCRS (s) should be given. If more than one point is defined, the intended use of all individual reference points should be given, together with an explanation of how a point is selected and indicated.

3.1.6 For all navigation parameters the manual and/or automatic backup and fall-back sequences when sensors become inoperable should be explained.

3.1.7 Instructions on setting basic display controls such as brightness, contrast, colour and day/night colour schemes should be given.

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3.2 Detailed operation (normal conditions)

3.2.1 The functions described should include all systems and subsystems that are part of the INS and any ship's functionality that can be controlled through the INS, such as the:

- navigation subsystems
- steering controls
- propulsion controls

3.2.2 Depending on the type of INS fitted the following specific information should be given:

- detailed operation of the automatic controls that are included, such as track controller functions
- the method(s) used to switch between operating modes and how to revert to manual operation
- the method of accessing the main/top-level display of all workstations and other INS equipment, including instructions to rapidly revert to such a display from whatever configuration has been set previously
- description of the displayed information on non-controllable displays, (if included within the installed configuration), e.g., a basic conning display
- the route planning and checking functions that are available
- the route monitoring functions that are available
- the operation of the Bridge navigational watch alarm facility, if fitted.

3.2.3 Where appropriate, for each function, the following information should be included:

- function name
- function description
- description of menu structure and displayed information
- description of operator controls
- required manually input information, if any
- description of how to configure task stations and user-modifiable displays and other data to user preferences. The method to rapidly revert to 'sensible' defaults must be given, even if it is considered that user configurations are not essential functions that need to be included as part of the familiarization material
- description of alerts and indicators, including mode indication. Procedural action on receiving alarms and warnings is covered in section 3.3
- the access of latency, integrity and accuracy data.

3.3 Detailed operation (abnormal and emergency conditions)

3.3.1 The following information should be included:

- details of conditions in which any automatic mode should not be used or should be used with certain restrictions or cautions
- identification of major failure alarms and warnings
- procedures involving the INS to follow on encountering alarms and warnings, other major failures, incidents or accidents, including:

  (i) reversion to a mode with lesser automation or to manual operation
  (ii) emergency disabling of functions that are causing or worsening the emergency.

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