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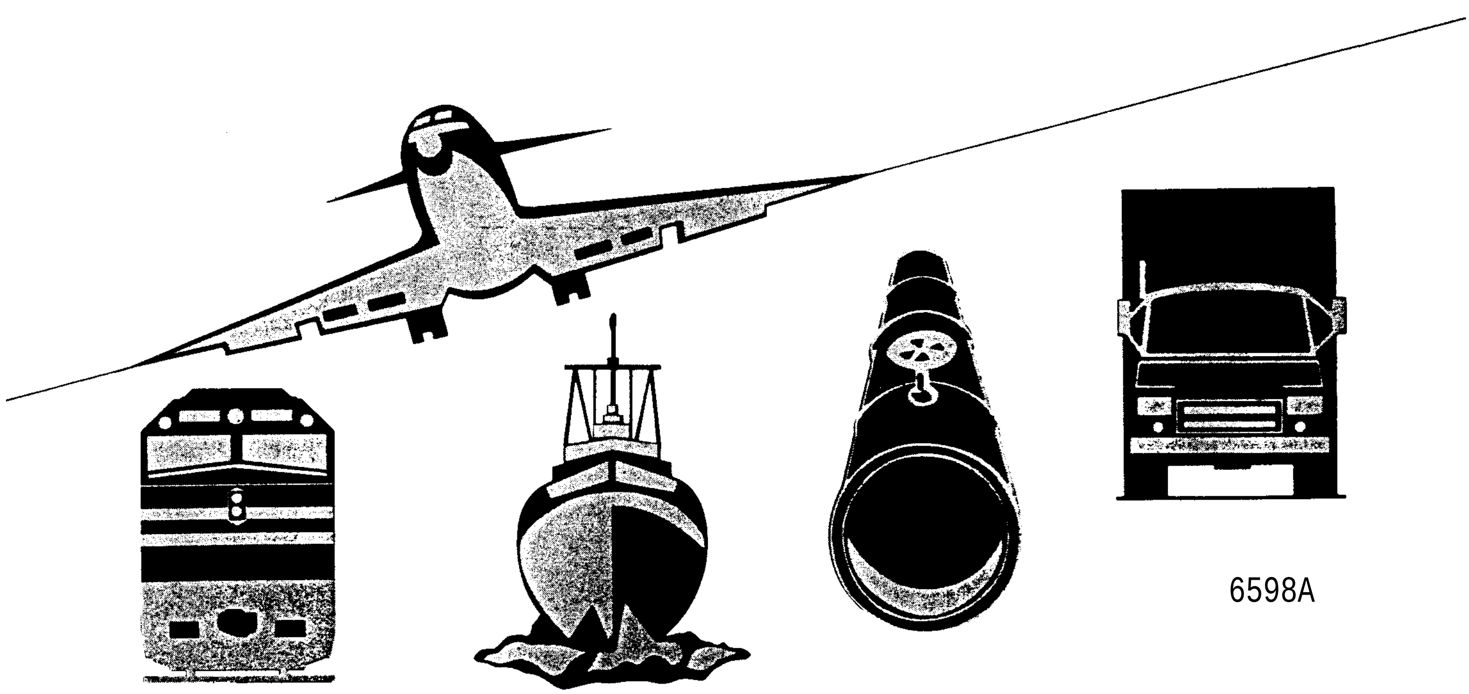
NATIONAL TRANSPORTATION SAFETY BOARD

WASHINGTON, DC 20594

MARINE ACCIDENT REPORT

GROUNDING OF THE PANAMANIAN PASSENGER SHIP *ROYAL MAJESTY* ON ROSE AND CROWN SHOAL NEAR NANTUCKET, MASSACHUSETTS JUNE 10, 1995



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Abstract: On June 10, 1995, the Panamanian passenger ship *Royal Majesty* grounded on Rose and Crown Shoal about 10 miles east of Nantucket Island, Massachusetts, and about 17 miles from where the watch officers thought the vessel was. The vessel, with 1,509 persons on board, was en route from St. George's, Bermuda, to Boston, Massachusetts. There were no deaths or injuries as a result of this accident. Damage to the vessel and lost revenue, however, were estimated at about $7 million.

This report examines the following major safety issues: performance of the *Royal Majesty*'s integrated bridge system and the global positioning system, performance of the *Royal Majesty*'s watch officers, effects of automation on watch officers' performance, training standards for watch officers aboard vessels equipped with electronic navigation systems and integrated bridge systems, and design, installation, and testing standards for integrated bridge systems.

As a result of its investigation, the National Transportation Safety Board issued safety recommendations to Majesty Cruise Line, the U.S. Coast Guard, STN Atlas Elektronik GmbH, Raytheon Marine, the National Marine Electronics Association, the International Electrotechnical Commission, the International Council of Cruise Lines, the International Chamber of Shipping, and the International Association of Independent Tanker Owners.

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GROUNDING OF THE PANAMANIAN PASSENGER SHIP *ROYAL MAJESTY* ON ROSE AND CROWN SHOAL NEAR NANTUCKET, MASSACHUSETTS JUNE 10, 1995

MARINE ACCIDENT REPORT

Adopted: April 2, 1997
Notation 6598A

NATIONAL TRANSPORTATION SAFETY BOARD

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EXECUTIVE SUMMARY

About 2225 on June 10, 1995, the Panamanian passenger ship *Royal Majesty* grounded on Rose and Crown Shoal about 10 miles east of Nantucket Island, Massachusetts. The vessel, with 1,509 persons on board, was en route from St. George's, Bermuda, to Boston, Massachusetts. Initial attempts to free the vessel were unsuccessful. Deteriorating weather and sea conditions prevented the evacuation of passengers and crewmembers from the vessel.

On June 11, the *Royal Majesty*, with the aid of five tugboats, was freed from its strand. Initial damage surveys revealed deformation of the vessel's double bottom hull. However, no penetration or cracking of the hull was detected, and no fuel oil had been spilled. The U.S. Coast Guard gave the vessel permission to proceed to Boston. On June 12, the vessel arrived in Boston and disembarked its passengers.

There were no deaths or injuries as a result of this accident. Damage to the vessel and lost revenue, however, were estimated at about $7 million.

The National Transportation Safety Board determines that the probable cause of the grounding of the *Royal Majesty* was the watch officers' overreliance on the automated features of the integrated bridge system, Majesty Cruise Line's failure to ensure that its officers were adequately trained in the automated features of the integrated bridge system and in the implications of this automation for bridge resource management, the deficiencies in the design and implementation of the integrated bridge system and in the procedures for its operation, and the second officer's failure to take corrective action after several cues indicated the vessel was off course.

Contributing factors were the inadequacy of international training standards for watchstanders aboard vessels equipped with electronic navigation systems and integrated bridge systems and the inadequacy of international standards for the design, installation, and testing of integrated bridge systems aboard vessels.

This report examines the following major safety issues:

- Performance of the *Royal Majesty*'s integrated bridge system and the global positioning system.
- Performance of the *Royal Majesty*'s watch officers.
- Effects of automation on watch officers' performance.
- Training standards for watch officers aboard vessels equipped with electronic navigation systems and integrated bridge systems.
- Design, installation, and testing standards for integrated bridge systems.

As a result of its investigation of this accident, the Safety Board issued safety recommendations to Majesty Cruise Line, the U.S. Coast Guard, STN Atlas Elektronik GmbH, Raytheon Marine, the National Marine Electronics Association, the International Electrotechnical Commission, the International Council of Cruise Lines, the International Chamber of Shipping, and the International Association of Independent Tanker Owners.

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INVESTIGATION

The Accident

About 2225[1] on June 10, 1995, the Panamanian passenger ship *Royal Majesty* (see figure 1) grounded on Rose and Crown Shoal near Nantucket Island, Massachusetts. The *Royal Majesty*, carrying 1,509 passengers and crewmembers, was en route from St. George's, Bermuda, to Boston, Massachusetts. No injuries or deaths resulted from the grounding.

On the night of the accident, the *Royal Majesty* was on the last day of a 7-day voyage. The ship had left Boston for Bermuda on June 5. The vessel had arrived in St. George's on June 7, where it was berthed until it departed Bermuda on June 9 for the return trip to Boston. The vessel was scheduled to arrive in Boston about 0530 on June 11.

The return trip to Boston was divided into two legs. The first leg normally extended from St. George's to the entrance of the approach to the Port of Boston Traffic Separation Scheme (Boston traffic lanes)—a distance of more than 500 miles over open ocean. The second leg normally took the vessel in a northerly direction through the traffic lanes along the eastern edge of Nantucket Shoals and around the eastern shores of Cape Cod. The entire voyage to Boston (a distance of about 677 miles—see figure 2) normally took about 41 hours.

The navigator testified that on June 9, he went on duty about an hour before the scheduled departure time of 1200. He said that he customarily tested the vessel's navigational equipment before getting underway. He stated that when he tested the navigation equipment, including "compasses, repeaters, radars, NACOS 25, GPS, Loran-C, and the communications systems" during the half hour before the vessel departed St. George's, he found the equipment to be in "perfect" operating condition. He said that shortly after departure, he set the navigation and command system (NACOS) 25 autopilot on the navigation (NAV) mode.[2] He further stated that later when the vessel dropped off the harbor pilot (about 1230), he compared the position data displayed by the global positioning system (GPS)[3] and by the Loran-C[4] and found that the two sets of position data indicated positions within about a mile[5] of each other.

According to the watch officers on duty, the northbound trip was uneventful during the first 24 hours. The watch officers stated that the *Royal Majesty* followed its programmed track, as indicated on the display of the automatic radar plotting aid (ARPA) maintaining a course of about 336°.[6]

[1]This report uses eastern standard times based on the 24-hour clock.

[2]A description of the vessel's radar and navigational equipment is contained in a section on vessel information later in the report. When set on the NAV mode, the NACOS 25 autopilot automatically corrected for the effect of set and drift caused by the wind, sea, and current to keep the vessel within a preset distance of its programmed track.

[3]The GPS is a satellite-based radio navigation system designed to provide continuous and accurate position data under all weather and sea conditions. The accuracy of the system is based on the GPS unit's ability to receive, identify, and measure radio signals from orbiting satellites. The GPS receiver on the *Royal Majesty*, when fully operational, was capable of providing position data accurate to within 100 meters to the NACOS 25 autopilot (see discussion later in this section).

[4]The Loran-C is a radio-based navigation system designed to provide position data along the coasts of the United States. The system is based on the Loran-C unit's ability to receive, identify, and measure time-difference radio signals from a series of land-based Loran stations. The accuracy of the system is largely dependent on the user's location in relation to the transmitting stations. For example, the Loran lines of position in the Bermuda area cross at oblique angles, whereas along the U. S. coast, numerous lines of position cross at much sharper angles to provide greater accuracy.

[5]In this report, the term *mile* means *nautical mile*.

[6]Unless otherwise specified, only true courses and bearings are noted in this report.

Figure 1—*Royal Majesty*.

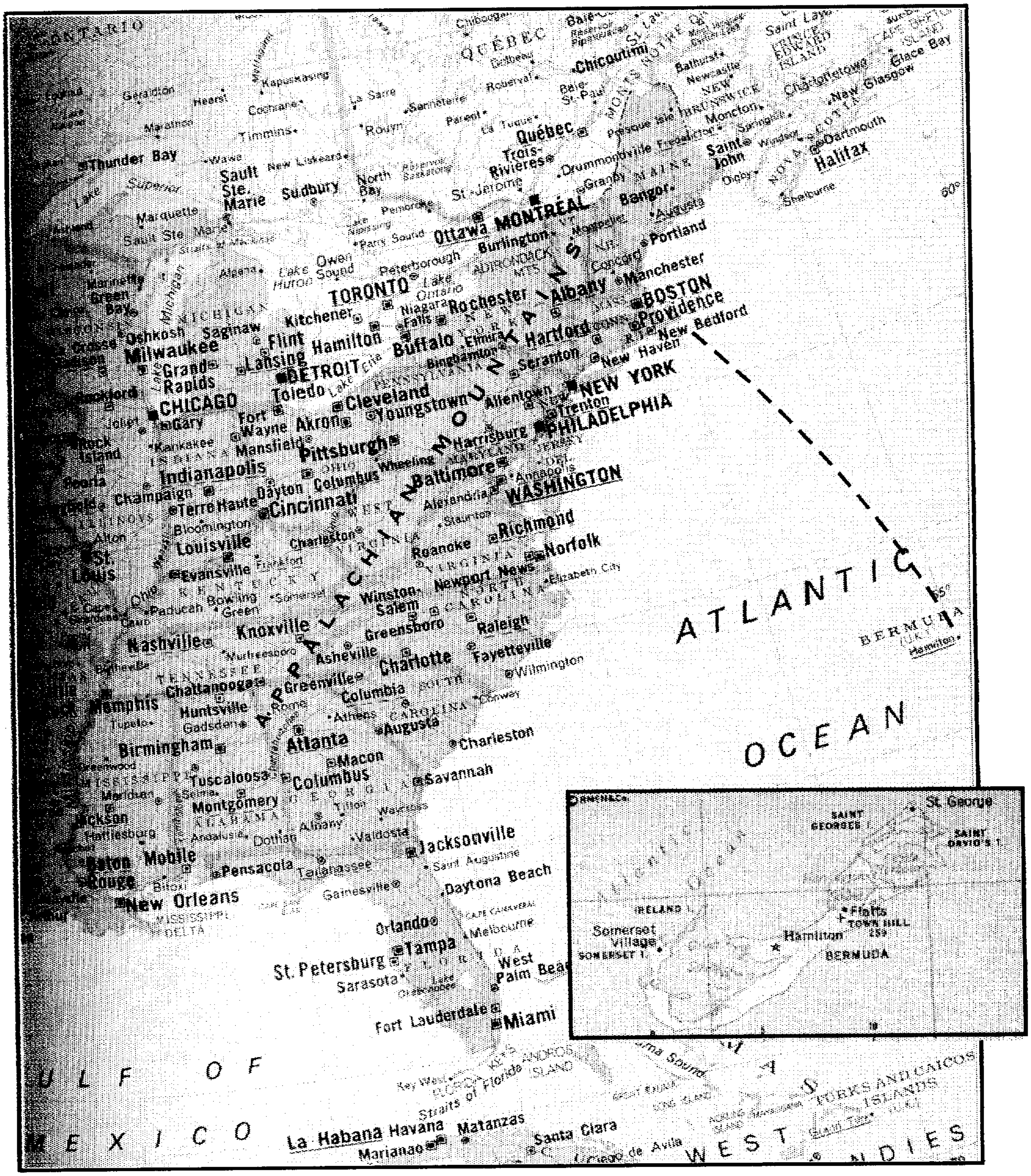


Figure 2—Map of route between Bermuda and Boston.

At 1200 on June 10, the navigator was again on watch, assisted by a quartermaster. According to the navigator, the *Royal Majesty* maintained its course of 336°, and its speed was 14.1 knots (over ground). Entries in the vessel's bridge log indicated cloudy skies, winds out of the east-northeast at 8 knots, and seas between 1 and 3 feet. Meteorological visibility was reportedly at least 10 miles.

The navigator stated that during his watch, he was using the port ARPA on the 12-mile-range scale. (See figure 3.) He also stated that he was plotting hourly fixes on the chart of the area using position data from the GPS. He stated that although he frequently checked the position data displayed by the Loran-C, all of the fixes that he plotted during the voyage from Bermuda were derived from position data taken from the GPS and not the Loran-C. (See figure 4. In the lower photograph, the lower receiver was installed after the accident.) The navigator further stated that in the open sea near Bermuda, the positions indicated by the GPS and Loran-C would have been expected to be within ½ to 1 mile of each other. As the vessel approached closer to the United States, the positions would have been expected to be within about 500 meters of each other.

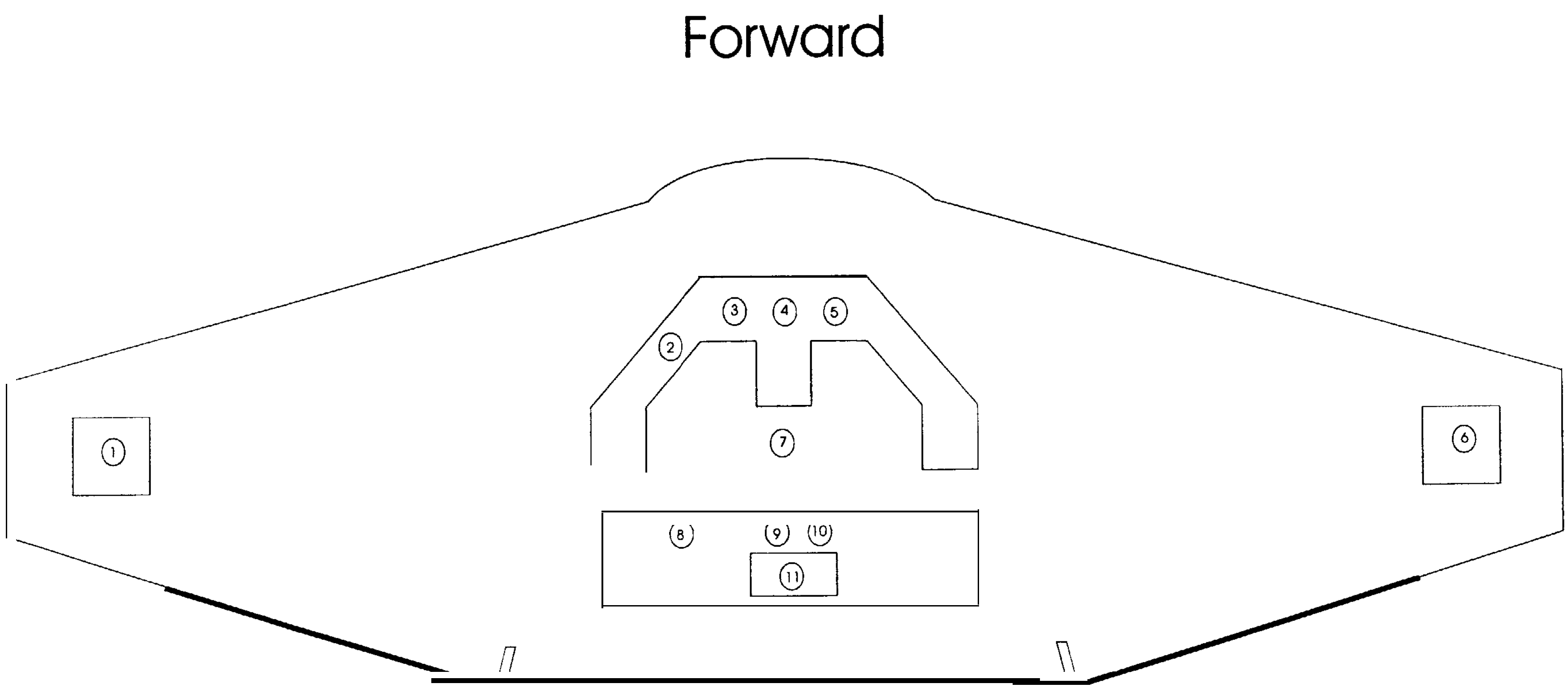
At 1600, the watch changed, and the vessel's chief officer relieved the navigator. The chief officer was assisted by a quartermaster, who acted as either a helmsman or a lookout on an as-needed basis. The chief officer stated that he used the port radar set on the 12-mile range. He further stated that no procedure specified the number of radars to use, but that usually two were used in bad weather. He stated that because the weather was good and visibility was clear, he used one radar. The chief officer also indicated that he relied on the position data from the GPS to plot hourly fixes during his watches and that the Loran-C was used as a backup system in case the GPS malfunctioned. He stated, however, that for the 1700 and 1800 hourly fixes he compared the data from the GPS with the data from the Loran-C and that in both instances the Loran-C indicated a position about 1 mile to the southeast of the GPS position.

The chief officer testified that before the 1700 hourly fix, at about 1645, the master telephoned the bridge and asked him when he expected to see the BA buoy, the buoy that marked the southern entrance to the Boston traffic lanes (see figure 5). The chief officer responded that the vessel was about 2½ hours away (35.25 miles at 14.1 knots) from the buoy. The master testified that he asked the chief officer to call him when he saw the buoy. According to the chief officer, about 45 minutes later (1730), the master visited the bridge, checked the vessel's progress by looking at the positions plotted on the chart and at the map overlay exhibited on the ARPA display, and asked a second time whether the chief officer had seen the BA buoy.[7] The chief officer responded that he had not. Shortly thereafter, the master left the bridge.

According to the chief officer, about 1845, he detected on radar a target off his port bow at a range of about 7 miles and concluded that the target was the BA buoy. He stated that his conclusion had been based on the GPS position data, which indicated that the *Royal Majesty* was following its intended track, and on the fact that the target had been detected about the time, bearing, and distance that he had anticipated detecting the BA buoy. He further testified that on radar the location of the target coincided with the plotted position of the buoy on the ARPA display. He said that about 1920, the radar target that he believed to be the BA buoy passed down the *Royal Majesty*'s port side at a distance of 1.5 miles. He stated that he could not visually confirm the target's identity because of the glare on the ocean surface caused by the rays of the setting sun.

He testified that about 1930, the master telephoned the bridge and asked him for the third time whether he had seen the BA buoy. According to the chief officer, he responded that

[7]The master testified that it was his practice to visit the bridge about 10 to 15 minutes after the change of the watch and that he typically called or visited the bridge between two and four times during each watch. Each visit to the bridge lasted between 10 and 15 minutes. He also testified that when he visited the bridge he typically checked the vessel's position by looking around and by examining the chart and the NACOS 25 map overlay on the ARPA.



1. Port Docking Station
2. Nacos 25 Display
3. Port ARPA/radar Display
4. NACOS 25 Autopilot
5. Starboard Arpa/Radar Display
6. Starboard Docking Station
7. Helm
8. Fathometer Recorder
9. Raytheon RAYSTAR 920 GPS Receiver
10. Raytheon RAYNAV 780 Loran C Receiver
11. Chart of the Area with Plotted Positions

Figure 3—Bridge layout.

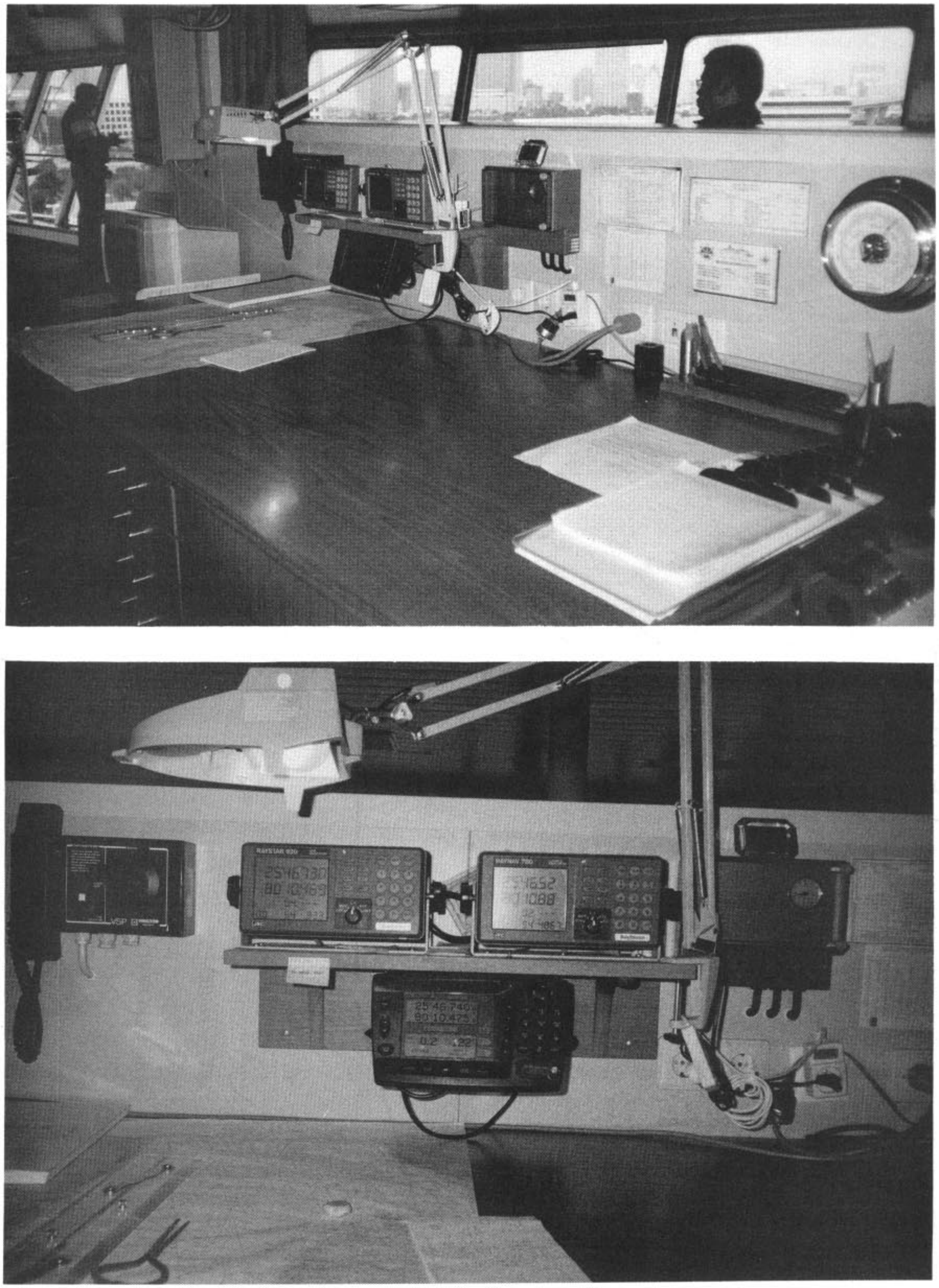


Figure 4—Two views of GPS and Loran C receivers.

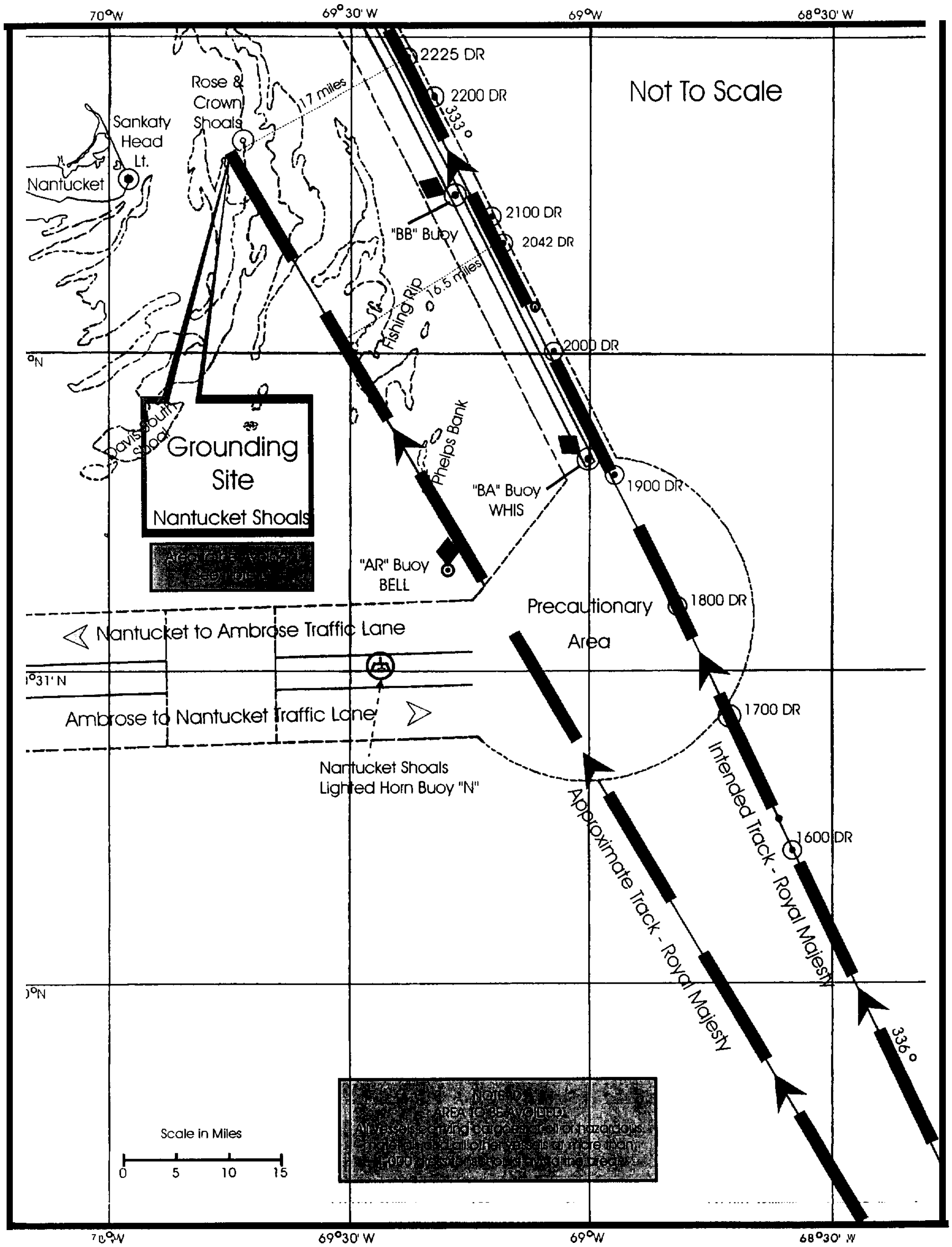


Figure 5-Intended track and approximately actual track.

the ship had passed the BA buoy about 10 minutes earlier (about 1920). The master then asked whether the chief officer had detected the buoy on radar; the chief officer replied that he had. According to the testimony of the chief officer and the master, the chief officer did not tell the master that he had been unable to visually confirm the identify of the BA buoy, and the master did not ask whether the buoy had been visually confirmed.

The second safety officer (second officer) testified that he arrived on the bridge about 1955 and prepared to assume the watch from the chief officer. According to the testimony of both officers, during the subsequent change-of-the-watch briefing (2000), they discussed the traffic conditions and the vessel's course, speed, and position. According to the testimony, the chief officer did not discuss with his relief the circumstances surrounding his identification of the BA buoy. The second officer testified that at 2000, he assumed the watch, assisted by two quartermasters,[8] and that the chief officer left the bridge. The second officer stated that shortly after assuming the watch, he reduced the range setting on the port radar from the 12-mile range to the 6-mile range. He testified that he relied on the position data from the GPS in plotting hourly fixes during his watches and that he considered the Loran-C to be a backup system. He also stated that it was not his practice to use the Loran-C to verify the accuracy of the GPS.

The quartermaster standing lookout on the port bridge wing (port lookout) stated that about 2030 he saw a yellow light off the vessel's port side and reported the sighting to the second officer. According to the quartermaster, the second officer acknowledged the report, but took no further action. At the time of the sighting, the NACOS 25 was showing the *Royal Majesty*'s position to be about halfway between the BA and BB buoys. (The BB buoy is the second buoy encountered when traveling northbound in the Boston traffic lanes.) Shortly after the sighting of the yellow light, both the starboard and port lookouts reported the sighting of several high red lights off the vessel's port side.[9] According to the lookouts, the second officer acknowledged the report, but took no further action.

The port lookout stated that shortly after the sightings of the yellow and red lights, the master came to the bridge. The master testified that he spent several minutes talking with the second officer and checking the vessel's progress by looking at the plotted fixes on the chart and the map overlay on the ARPA display. According to the master, the GPS and ARPA displays were showing that the vessel was within 200 meters of its intended track. The master then left the bridge. According to the testimony of both the master and the second officer, no one told the master about the yellow and red lights that the lookouts had sighted earlier.

The master testified that about 2145, he telephoned the bridge and asked the second officer whether he had seen the BB buoy. The master stated that the second officer told him that he had seen it.

According to the master, about 2200 he arrived on the bridge for the second time during that watch. He testified that after talking with the second officer for several minutes, he checked the vessel's progress by looking at the positions plotted on the chart and at the map overlay on the ARPA display. He stated that he again asked the second officer whether he had seen the BB buoy and the second officer replied that he had. Satisfied that the positions plotted on the chart and that the map displayed on the radar continued to show the vessel to be following its intended track, the master left the bridge about 2210. He stated that he did not verify the vessel's position using either the GPS or the Loran-C for two reasons: (1) his officers had reported that the BA and BB buoys had been sighted, and (2) he had observed that the map overlay on the ARPA display showed that the vessel was following its intended track.

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[8] The two quartermasters served as port and starboard lookouts.

[9] A series of radio towers with flashing red lights are on the eastern end of Nantucket. Because the towers are about 30 miles from the traffic lanes, the lights are not generally visible to vessels transiting the traffic lanes.

The second officer testified that he had not seen the BB buoy but had informed the master otherwise because he had "checked the GPS and was on track" and because "perhaps the radar did not reflect the buoy." He also testified that on the previous transits of the traffic lanes, he had sighted buoys both visually and by radar.

According to the testimony of the lookouts, a few minutes after the master left the bridge, the port lookout reported to the second officer the sighting of blue and white water dead ahead. According to this lookout, the second officer acknowledged receiving the information, but did not discuss it or take action. The port lookout stated that the vessel later passed through the area where the blue and white water had been sighted.

The second officer testified that about 2220, the *Royal Majesty* unexpectedly veered to port and then sharply to starboard and heeled to port. The second officer stated that because he was alarmed and did not know why the vessel was sheering off course, he immediately switched from autopilot to manual steering. The master, who was working at his desk in his office, felt the vessel heel to port and ran to the bridge. He stated that when he arrived on the bridge, he saw the second officer steering the ship manually and instructed one of the lookouts to take over the helm. The master then turned on the starboard radar, set it on the 12-mile range,[10] and observed that Nantucket was less than 10 miles away. According to the master, he immediately went into the chart room to verify his position. He stated that he then immediately ordered the helmsman to apply hard right rudder. However, before the helmsman could respond, the vessel grounded, at 2225. The master stated that he then had the vessel's GPS and Loran-C checked and realized for the first time that the GPS position data was in error by at least 15 miles. The Loran-C position data showed the vessel where it had grounded, about 1 mile south of Rose and Crown Shoal.[11] (See figure 6.) Charts of the area indicate that the shoal, which is about 10 miles east of Nantucket's Sankaty Head Light, has a hard sandy bottom.

Postaccident Events

The master testified that immediately after the grounding, he called the engineroom and told the engineering officer on duty that the vessel had grounded and that he should immediately inspect the vessel's double bottom hull and fuel tanks for signs of leakage. According to the master, several minutes later, the engineroom called the bridge and reported that there was no evidence that the vessel was taking on any water. The master responded by asking the engineroom personnel to repeat the inspection, which they did. The master stated that about 2245 the engineroom again reported to him that no evidence of leakage had been found. Shortly thereafter, the master instructed the vessel's cruise director to inform the passengers and crewmembers that the vessel had run aground, that it was not in any danger, and that the crew was trying to free the vessel by using its engines. At 2310, the U.S. Coast Guard, after receiving a message from a passenger via cellular telephone, called the *Royal Majesty*, at which point the *Royal Majesty* requested Coast Guard assistance. According to the testimony of the master, he had been about to notify the Coast Guard when the Coast Guard called him.[12]

Several unsuccessful attempts were made between 2245 and 0015 to free the vessel using the main engines. Shortly thereafter, Majesty Cruise Line, the owner of the vessel, made

[10] According to the master, the starboard radar was typically turned off during good weather. When he used the starboard radar, he normally set it on the 12-mile range. He further stated that no procedures prescribed the radar scale to use; it was the option of the watch officer on duty.

[11] Rose and Crown Shoal is one of numerous shoals that lie east and south of Nantucket Island, making the area one of the most dangerous for ships. (See "Waterway Information" later in this report for a more detailed discussion.)

[12] According to 46 *Code of Federal Regulations* 4.05-1(a), immediately after the addressing of resultant safety concerns, the owner, agent, master, operator, or person in charge shall notify the nearest Marine Safety Office, Marine Inspection Office, or Coast Guard Group Office whenever a vessel is involved in a marine casualty consisting of an unintended grounding. According to the Coast Guard, the time interval was reasonable and the Coast Guard took no enforcement action regarding the notification.

Figure 6—*Royal Majesty* aground.

arrangements to hire tugboats to pull the vessel off the shoal.

At 0024 on June 11, the passengers were told that the efforts to free the vessel had been unsuccessful and that the vessel was awaiting the arrival of tugboats. Later that morning, the passengers were told that they and their luggage would be transferred to ferries for transport to Hyannis, Massachusetts, and then to Boston.

At 1330 on June 11, the ferries M/V *Brant Point* and *Point Gammon* arrived on scene.[13] The *Brant Point* and *Point Gammon* together could hold about 1,200 persons.

At 1550, the tugboats *Vincent Tibbets*, *Harold Rheinhauer*, *Resolute*, *Reliance*, and *Venus* arrived on scene. Meanwhile, sea conditions continued to deteriorate. About 1600, plans to offload passengers to the ferries were canceled because sea conditions had become too hazardous. Shortly thereafter, the *Brant Point* and the *Point Gammon* returned to Hyannis.

At 2154, the *Royal Majesty*, with the aid of five tugboats, was refloated and escorted to a safe anchorage near Chatham, Massachusetts, where the damage was surveyed. At 0742 on the morning of June 12, the Coast Guard gave the vessel permission to begin the 6-hour trip to Boston. At 1535, the vessel was safely moored with its port side to the Black Falcon Passenger Terminal in Boston. Passengers began disembarking the vessel at 1710.

The Coast Guard/Safety Board hearing into the grounding of the *Royal Majesty* was held June 14 through June 16 in Boston. After the hearing, the Safety Board learned that two fishing vessels were just east of Fishing Rip Shoal on the evening of June 10. They observed a cruise ship pass about ¾ mile west of the fishing vessels' position heading in a northerly direction. About 2042, one of the fishing vessels radioed a cruise ship at "41 02N, 69 24W" via VHF-FM channel 16. They later stated it was their intent to inform the vessel that it was in an area not frequented by large cruise ships. The calls to the cruise ship were in English; however, all the transmissions between the fishing vessels, including the transmission regarding the ship being in the wrong location, were in Portuguese. An unknown person interrupted the Portuguese conversation and requested that the fishermen change channels. (See appendix F.)

According to international regulations (SOLAS-Regulation 8), when ships such as the *Royal Majesty* are at sea they are required to maintain a continuous listening watch on the navigating bridge on 156.8 MHz (channel 16). During the Coast Guard Marine Board of Inquiry, the second officer was not asked whether he was monitoring channel 16 on the night of the accident.[14] Since that time, a spokesperson for Majesty Cruise Line has identified the person who interrupted as possibly the second officer. The Safety Board could not confirm this. According to the Coast Guard, the call to the cruise ship from the fishing vessel did not convey any urgency and would not have alerted the second officer aboard the *Royal Majesty* or the radio operator at U.S. Coast Guard Group Woods Hole, where the transmissions were recorded, that the *Royal Majesty* or any other cruise ship was in danger.

Injuries

The accident did not cause any deaths or injuries.

Vessel Damage

On June 16, the *Royal Majesty* left Boston for the Sparrows Point Shipyard in Baltimore, Maryland, where it was drydocked and repaired. The grounding of the *Royal Majesty* had damaged its outer hull extensively. According to the field survey conducted by Lloyds Register on June 19, a portion of the vessel's outer shell plating, which was about 51 feet wide and 41 feet long, needed to be cropped and renewed. The report also indicated that the bottom fuel oil

[13] Hyline Cruises in Hyannis, Massachusetts, owned and operated the two ferries. Hyline Cruises operates a ferry service between Cape Cod and Nantucket and Martha's Vineyard.

[14] The second officer was released by Majesty Cruise Line after the accident and is not available in this country.

tanks and the internal steel structure between the vessel's internal tank tops and hull plating had been substantially damaged. No oil spilled as a result of the accident.

On June 22, the vessel was refloated and returned to Boston. On June 24, the vessel resumed passenger service. Total structural damage was estimated at about $2 million. Lost revenue for the period the vessel was out of service was estimated at about $5 million.

Crew Information

Master.—The master, age 53, held a master's certificate for seagoing vessels that had been issued by Panama on June 7, 1991. He also held a master's certificate from the Greek government that was originally issued in 1974. He had been going to sea for 32 years. During his career, he had served in a variety of licensed deck officer positions on tankships and passenger ships. Between 1968 and 1992, he had sailed as chief officer and master on several passenger vessels built in the 1950s. Majesty Cruise Line assigned him as master of the *Royal Majesty* in November 1992. He stated that the *Royal Majesty* was the first vessel that he had served on that had an integrated bridge system.[15]

The master testified that he had not consumed any alcohol before the grounding, that he had not taken any prescription medicine, and that he was not required to wear eyeglasses. He stated that he typically slept about 7 hours each night, from 2400 to 0700, and then took a 1-hour or 1½-hour nap in the afternoon, schedule permitting.

Chief Officer.—The chief officer, age 43, held a master's certificate for seagoing vessels that had been issued by Panama on May 20, 1994. He also held a chief officer's certificate issued by the Greek government in 1982. He had been going to sea since 1971. During his career, he had served in a variety of licensed deck officer positions on cargo ships, tankships, and passenger ships. Between 1981 and 1992, he had been chief officer on four passenger vessels built in the 1950s. Majesty Cruise Line hired him as chief officer on the *Royal Majesty* in 1992. The *Royal Majesty* was the first vessel he had served on that had an integrated bridge system. At the time of the grounding, he had spent 30 of the previous 36 months as a bridge watch officer aboard the *Royal Majesty*.

The chief officer stated that routinely after finishing his 1600-to-2000 watch, he would jog on deck (weather permitting) for about 45 minutes, work out in the vessel's gym for about 15 minutes, and retire around 2200. He normally slept until about 0330. He stated that typically he also slept about 2½ hours before starting his 1600 watch.

Navigator.—The navigator, age 30, held a second officer's certificate for seagoing vessels that had been issued by the Greek government on May 18, 1994. He also held a second officer's license from Panama. He had been going to sea in a licensed capacity since March 20, 1987. During his career, he had served 8 months as second officer on a tankship and 7 months as second officer on two passenger ships that had been built in the 1950s. Majesty Cruise Line hired him as a second officer on the S/S *Seabreeze* on July 18, 1994. He was assigned as navigator aboard the *Royal Majesty* on August 1, 1994. The *Royal Majesty* was the first vessel that he had served on that had an integrated bridge system.

The navigator testified that he had not consumed alcohol in the 24 hours before his last watch, that he was not taking any prescription drugs, and that he was not required to wear eyeglasses.[16]

Second Officer.—The second officer, age 33, held a chief officer's certificate for seagoing vessels that had been issued by the Greek government on January 4, 1991. He also held a chief officer's license from Panama. He had been going to sea in a licensed capacity since May 1984. During his career, he had served in a variety of licensed deck officer positions on

[15] "Vessel Information," the next section of the report, discusses integrated bridge systems.

[16] There was no information in the navigator's testimony about the amount of sleep he received in the 24 hours before his last watchstand or about his sleep pattern.

bulk carriers and passenger ships. He had sailed as second officer and chief officer on five passenger vessels between 1987 and 1994. Majesty Cruise Line hired him as a second officer on May 1, 1995. After 3 weeks of on-the-job training, the master allowed him to stand a navigation watch alone. On May 21, 1995, he assumed his duties as watch officer for the 0800-to-1200 watch. The *Royal Majesty* was the first vessel that he had served on that had an integrated bridge system.

The second officer testified that he had not consumed alcohol or taken any prescription medicine in the 24 hours before his last watch. He stated that he slept about 7 hours after finishing his previous 2000-to-2400 watch and that he had also taken a 2-hour nap before beginning his 2000 watch on June 10.

Vessel Information

General.—The *Royal Majesty* was a conventional steel-hull, bulbous-bow, passenger liner designed for unrestricted international voyages. The vessel was constructed in 1992 at Kvaener Masa Yard in Turku, Finland. Panama had certified the vessel to carry 1,256 passengers and 490 crewmembers, a total of 1,746 persons. The vessel held the highest vessel classification for construction issued by Det Norske Veritas (DNV). The vessel's principal characteristics follow:

Length overall:	568 feet (173.16 meters)
Breadth:	91 feet (27.60 meters)
Draft (departure Bermuda):	forward: 18 feet, 0.5 inches (5.5 meters); aft: 19 feet, 6 inches (5.95 meters)
Gross registered tonnage:	32,396
Displacement:	17,214 tons
Service speed:	19 knots
Propellers:	two controllable pitch

The *Royal Majesty* was fitted with the following navigation, communications, shiphandling, and collision-avoidance equipment:

Radar:	Two Krupp Atlas[17] Model 8600 A/CAS with ARPA
Radar:	One Krupp Atlas slave radar with ARPA
Autopilot:	STN Atlas Elektronik
GPS:	Raytheon RAYSTAR 920 with dead-reckoning backup mode option installed (NNE-205 DR interface)
Loran-C:	Raytheon RAYNAV 780
VHF radios:	Two Sailor radios (with dual monitoring capabilities)
Speed log:	Atlas Dolog 23
Gyro compass:	Anschutz
Course recorder:	Anschutz

Integrated Bridge System.—The *Royal Majesty* had an integrated bridge system. According to the definition of the International Electrotechnical Commission (IEC),[18] issued after the vessel was built, an integrated bridge system is a combination of systems that are integrated in order to allow centralized access to sensor information and command/control from workstations. One of the main components of the vessel's integrated bridge system was STN Atlas Elektronik (STN Atlas) NACOS 25.[19] The NACOS 25 was a special upgrade of the first generation NACOS 20 integrated navigation system, of which approximately 130 have been sold and installed on vessels of various types and service. The NACOS 25 was specifically designed for service on six Baltic Sea ferries constructed at Kvaener Masa Yard. Some were sold to Italian vessel owners. According to STN Atlas, 14 NACOS 25 units were sold to owners of passenger ships. The last unit was sold in May 1988 to the shipyard constructing the *Royal Majesty*. However, because of construction delays, the *Royal Majesty*'s NACOS 25 equipment

[17]Krupp Atlas was the previous name of STN Atlas Elektronik.

[18]A later section of the report discusses the IEC and integrated bridge systems in general.

[19]According to STN Atlas, 260 such units have been sold worldwide; 200 are currently in service. (*Safety At Sea*. June 1995, page 36.)

was held in stock until installation in the spring of 1992.

The *Royal Majesty*'s NACOS 25 was capable of creating radar maps and exhibiting them on the ARPA display (see figure 7). The radar maps could be tailored to include reference points along the vessel's intended track (aids to navigation, navigation marks, waypoints, turning points, etc.). Navigation lines could also be added to these maps for the purpose of outlining the perimeter of traffic lanes, channels, and areas containing hazards to safe navigation.

The navigator testified that a radar map had been created for the voyage between St. George's and Boston. He also testified that the map, showing the vessel's preprogrammed track, waypoints, and the location of the buoys near the intended track, was exhibited on the ARPA display before the accident.

The autopilot portion of the NACOS 25, using programmed information (latitude and longitude of waypoints and the vessel's maneuvering characteristics), gyro and speed data, and position data from the GPS or the Loran-C, was capable of automatically steering the vessel along a preprogrammed track. When engaged and operating in the NAV mode, the autopilot steered the ship in accordance with the programmed track while automatically compensating for the effect of gyro error, wind, current, and sea. According to the *Royal Majesty*'s bridge officers, the NACOS 25 autopilot was engaged and operating in the NAV mode from the time the vessel departed St. George's (1400 on June 9) to before the grounding.

The Raytheon GPS unit installed on the *Royal Majesty* had been designed as a standalone navigation device in the mid- to late 1980s, when navigating by dead reckoning (DR)[20] was common and before the GPS satellite system was fully operational. The GPS unit was designed to default to either a DR mode or a hybrid navigation mode (accepting position data from a Loran-C, Omega, or Transit satellite navigation receiver). The *Royal Majesty*'s GPS was configured by Majesty Cruise Line to automatically default to the DR mode when satellite data were not available.[21] When the RAYSTAR 920 GPS unit switches to DR mode, it

- issues a series of aural chirps similar to those of a wristwatch alarm (the total duration of the series is 1 second);
- continuously displays *SOL* (solution)[22] and *DR* on a liquid crystal display; the display measures 3 inches high by 3.5 inches wide (see figure 8);
- changes the state of National Marine Electronics Association (NMEA)[23] 0183 status field bits from *valid* to *invalid*, indicating that valid position data are no longer being transmitted; and
- closes an electronic switch that is provided as a means of activating an external alarm or other device of the installer's choice (such as an external flashing light, audio alarm, etc.).[24]

[20] *DR* is a means of navigating. After an initial position is established, the position is estimated over time using data input from the vessel's speed log and gyro. The accuracy of DR calculations depends on the accuracy of the speed input and the effects of wind and current.

[21] RAYSTAR 920 DR mode capability requires course and speed input either by manual entry or via an optional interface box. The *Royal Majesty*'s RAYSTAR 920 was configured to use the DR interface box. According to STN Atlas, during the construction of the *Royal Majesty*, STN Atlas was told that the GPS would be backed up by a Loran-C system during periods of GPS data loss, but was not told that the GPS receiver would default to the DR mode.

[22] Raytheon engineers informed the Safety Board that *SOL* is meant to indicate that the GPS satellite position solution is invalid or not available. According to the Raystar 920 operation manual, *SOL* means the unit cannot calculate its lat/long position.

[23] The NMEA 0183 is an industry-standard electronic signal specification that defines how data are to be transmitted from an electronic device.

[24] An external alarm was not connected to this switch on the *Royal Majesty*.

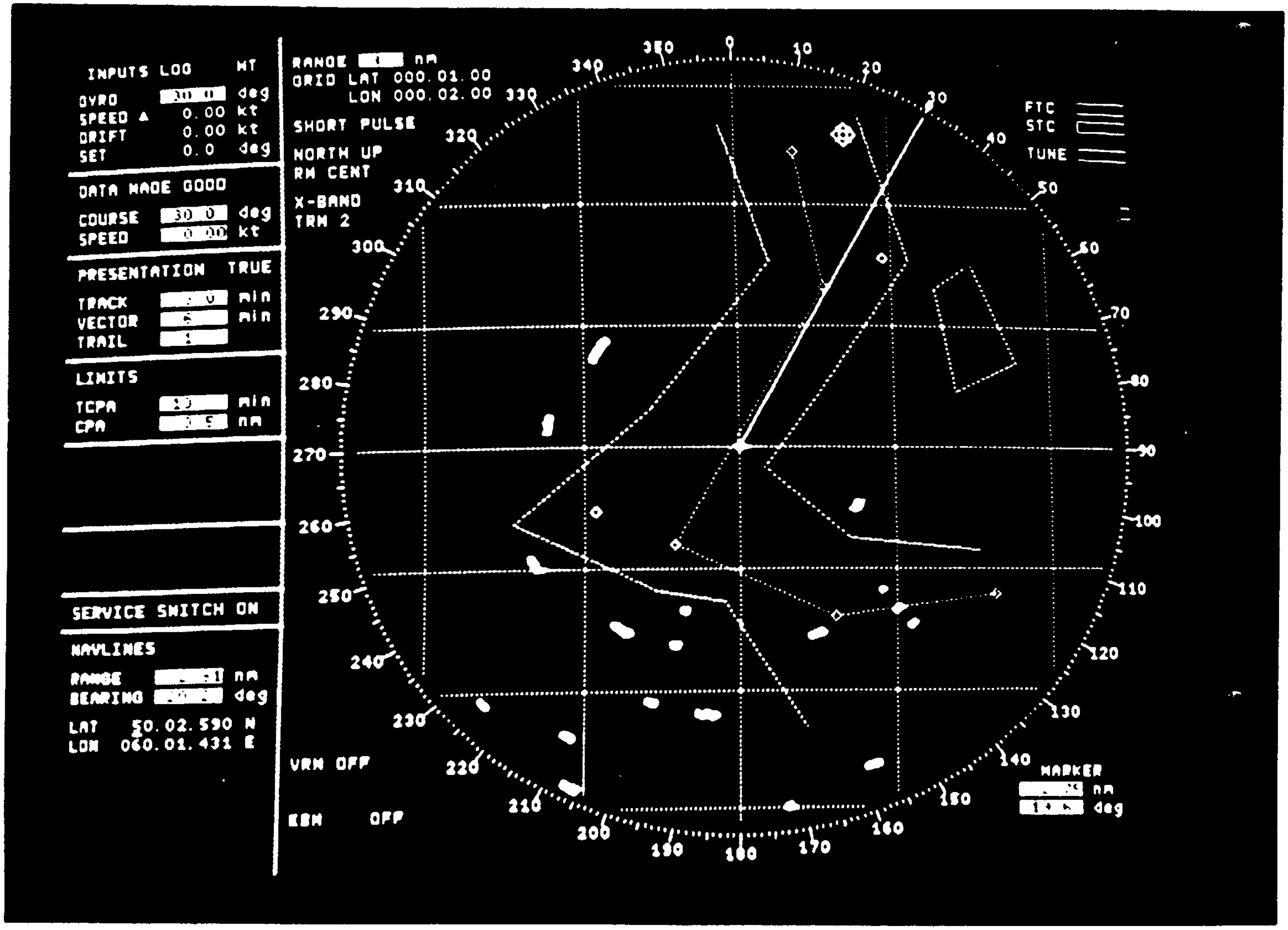


Figure 7—Sample map on ARPA display.

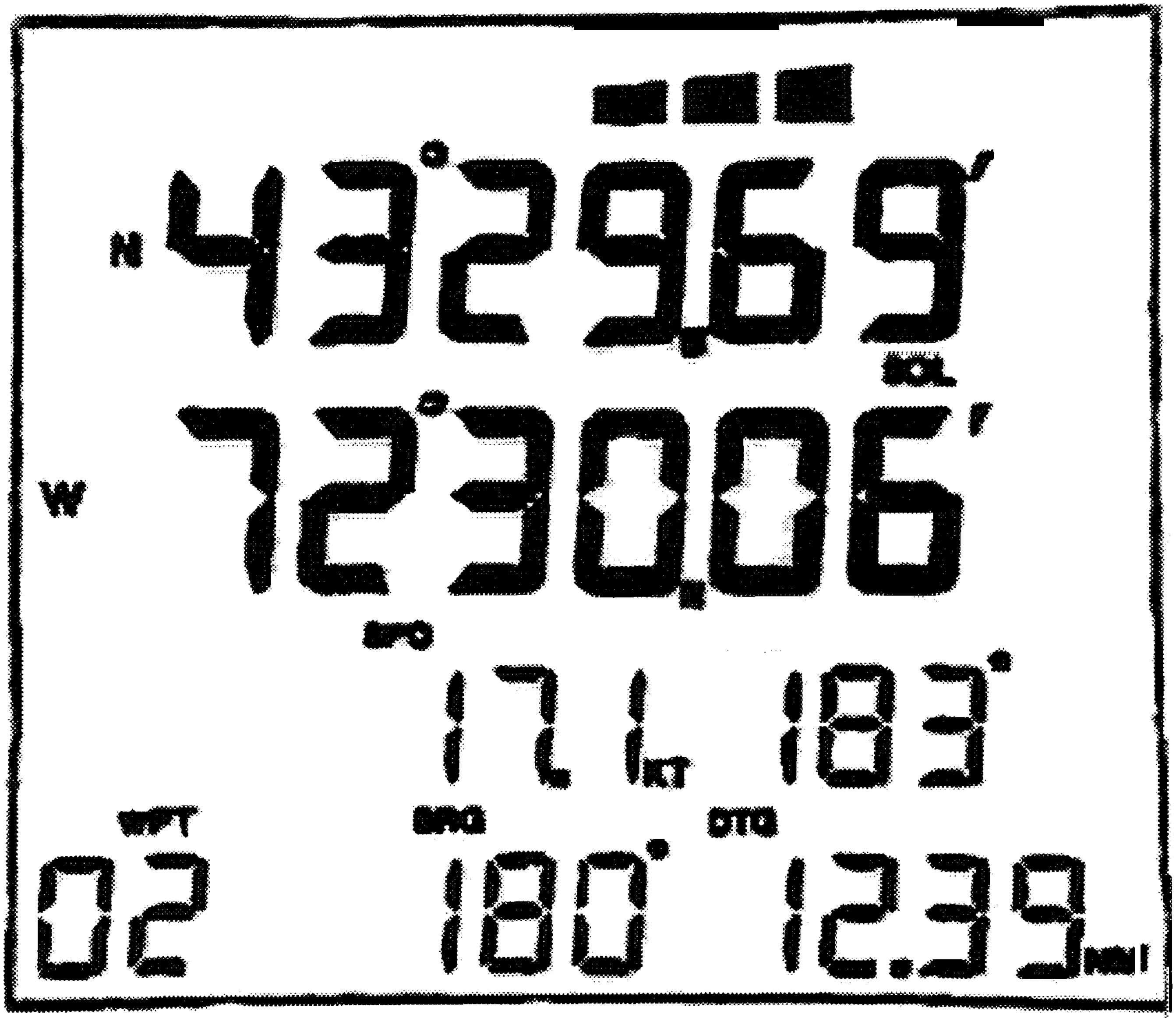


Figure 8—GPS display showing *SOL* and *DR.*

All the watch officers testified that they did not see *SOL* and *DR* displayed on the GPS unit during their watches before the grounding. Their testimony indicated that they understood the meaning of these symbols and had seen them on previous occasions.

The Raytheon RAYSTAR 920 GPS and the Raytheon RAYNAV 780 Loran-C were designed to output position and other navigation data in NMEA 0183 v1.5 format.[25] The output included the recommended minimum GPS data sentence, *RMC*, which contained, among other data, latitude/longitude position coordinates.[26] A position receiver that transmits data is a "talker" device in NMEA nomenclature; the Raytheon 920 GPS identified itself as a GP talker, which signified a GPS position receiver sending GPS position data. A position receiver such as the Raytheon 920 GPS, while operating in different position modes, could identify itself as an integrated instrument (II) talker. At the time the system was designed, the NMEA specified a *SYS* sentence to identify the operational mode of a hybrid system. The *SYS* sentence defines the mode in which the receiver is operating: GPS (G), Loran (L), Omega (O), Transit (T), or Decca (D). However, DR is not a specified system mode in the NMEA 0183 *SYS* sentence. Thus, Raytheon designed the 920 GPS to identify itself as a "GP" talker regardless of GPS or DR mode and used the NMEA 0183 *valid*/*invalid* data bits as the means of notifying "listeners" that its data were invalid when in DR mode. However, the sentence formatter *GDP* was available in NMEA 0183 v1.5 to indicate dead reckoned geographic position fixes.

Although both the GPS and Loran-C simultaneously sent position data to the NACOS 25, the NACOS 25 was designed to use position data from only one external position receiver at a time, as selected by the crew. That is, the NACOS 25 was not designed to compare the GPS and the Loran-C position inputs, nor was it designed to display both sets of position data to the bridge officers simultaneously so that they could compare the data. On June 9 and throughout the voyage, the autopilot was set by the crew to accept and display position data from the GPS receiver, which was the position receiver normally selected by the crew during the 3 years the vessel had been in service.

Once the position receiver is selected, the NACOS 25 recognizes the chosen position receiver based on the talker identifier codes in the NMEA 0183 data stream; for example, *GP* in the data stream from the Raytheon 920 GPS. According to STN Atlas, its designers did not expect a device identifying itself as GP to send position data based on anything other than GPS satellite data, particularly not DR-derived position data. Further, STN Atlas expected invalid GPS position data to be recognizable by nulled position data fields, by halted data transmission, by a separate proprietary *SLL* sentence,[27] or by no changes in the position latitude/longitude. The latter case would trigger the NACOS position-fix alarm; the other cases would cause the NACOS to switch its position input to *estimated* (its own DR mode) and to highlight this information at all NACOS and radar displays until the transmission is resumed and/or the *SLL* sentence contains the valid data bit.

According to the NMEA, NMEA 0183 provides three methods to indicate whether the transmitted data are inaccurate or unavailable: (1) null fields where the sentence is transmitted but no data are inserted in the fields in question; (2) by using system-specific status sentences (available only for Loran-C; and (3) by the use of "status" or "quality indicator" characters in specific sentences. There are no other provisions within NMEA 0183 to indicate invalid data in transmitted sentences. In version 1.5, the use of

[25] NMEA 0183 v1.5 was released in December 1987.

[26] According to STN Atlas, the NACOS, at the time of delivery for *Royal Majesty*, was programmed to read the NMEA 0183 v1.1 sentence *GLL* (geographic longitude/latitude) for position input. The sentence *RMC* was only introduced with the NMEA 0183 v1.5 after the design of the Radar Atlas 8600 was finished. (The radar provides the interfaces to the position receiver(s), in a NACOS system.)

[27] NMEA 0183 provides proprietary data sentences for special use between devices produced by the same manufacturer, but not between devices by two different manufacturers unless the two different manufacturers have coordinated use of such data sentences.

null fields is the most common method, as most sentences do not have status fields. According to STN Atlas's interpretation of this specification, when a position receiver with a GPS talker identifier has no GPS position data available, it must transmit null fields instead.

The NACOS 25 autopilot was programmed to continuously calculate its own independent DR position in order to provide a comparison with the position data provided by the external position receiver (GPS or the Loran-C in the case of the *Royal Majest*y). If the autopilot's DR position and the external position-receiver's position (GPS or Loran-C positions in the case of the *Royal Majesty*) are within a specified distance of each other,[28] the autopilot considers the position data from the external position receiver to be valid, makes any necessary course corrections, and uses the new external position receiver's position to continue its own independent DR calculations. If, however, the two positions are more than the specified distance apart, the autopilot sounds a loud alarm[29] and presents a visual indication (*warning position fix*) on all the NACOS displays, including the radars, meaning that a position discrepancy has been detected that requires the watch officers' immediate attention. If the lateral distance between the GPS position and the preprogrammed track line exceeds the specified distance, the autopilot sounds a loud alarm and presents a visual indication (*warning track limit exceeded*) on the NACOS display, meaning that the vessel is off the intended track.

The navigator stated that during the 11 months he had been aboard the vessel, he had observed a phenomenon he called "chopping." Other deck officers stated that they too had witnessed this phenomenon. According to the navigator, chopping occurred when, for whatever reason, the position data displayed by the GPS were unreliable. Majesty Cruise Line's electronics technician and the Raytheon staff indicated that chopping could have been the result of atmospheric interference with GPS signals or the obstruction of the GPS antenna's view of the satellites by the vessel's superstructure and/or tall buildings or other structures while the vessel was in port. These circumstances degraded the GPS signal, changing the calculated position, and consequently caused the radar map display to jump erratically, which the crew referred to as chopping.

According to the navigator's testimony, when chopping occurred, the 1-second series of aural chirps sounded and *SOL* and *DR* appeared on the GPS display. The master testified that chopping also usually set off the NACOS 25 position-fix alarm, indicating that the difference between the NACOS 25 DR position and the GPS position was greater than 200 meters. He stated that watchstanders had found, through trial and error, that if they acknowledged the alarm before switching to the COURSE mode,[30] the autopilot automatically accepted the erroneous position data and the radar map moved about the ARPA display. To avoid this, watchstanders switched the autopilot from the NAV mode to the COURSE mode before acknowledging the alarm. Thus, they could use the map until the GPS returned to normal. According to the master, chopping generally lasted a few minutes. Nothing in the testimony of the watch officers suggested that chopping had occurred during the trip from Bermuda to Boston.

According to Majesty Cruise Line, the GPS antenna, originally installed on the radar mast, had been moved in February 1995, several months before the grounding, as part of an effort to eliminate the chopping. Majesty Cruise Line's electronics technician indicated that as a result of the move, the antenna's view of the satellites was less obstructed and the crew complained much less about chopping.

[28]The NACOS 25 autopilot has off-track and position-fix alarms that allow the operator to set the off-track and position-comparison limits anywhere between 10 and 990 meters. On the day of the accident, the limit was set at 200 meters. This value, which is displayed to the crew as *TRACK LIMIT*, is used for both the off-track and the position-fix alarm calculations.

[29]The alarm is designed to be audible within a range of about 10 meters under normal ambient noise conditions.

[30]In COURSE mode, the NACOS 25 system steers a selected course while correcting for drift using the Doppler log traverse speed component.

The *Royal Majesty*'s integrated bridge system was also fitted with an automatic bell logger (bell log), which was located against the after bridge bulkhead. At regular intervals, the bell log recorded the propeller pitch settings, engine revolutions per minute, true course, and speed. It also recorded the time of each entry in Greenwich mean time.[31] The course and speed data that were recorded by the bell log came from the vessel's GPS.

The bell log showed that it was turned on at 1131:54 on June 9. Between 1131:55 and 1133:17, the bell log recorded a course of 197°, 000°, and 197°, indicating that the GPS data were invalid. This could be the result of the GPS receiver being turned on and going through its satellite acquisition process, chopping, antenna connection problems, or other problems. The record also showed that between 1133:18 and 1202, the *Royal Majesty* was steering various courses. Between 1130 and 1202, the vessel was still moored alongside the pier.[32] Such course variation while the vessel is stationary is consistent with normal GPS position variation and the resulting calculation of courses between those slightly different positions. The bell log recorded various courses between 1203, when the ship left the pier, and 1252, consistent with port departure. At 1252:02, the bell log once again began recording consecutive courses of 197° and 000°, when, in fact, the vessel was steering a course of 333°, as shown by the ship's course recorder. At 1309:06, the bell log recorded a course of 336°. After that recording, the bell log recorded 197°/000° headings continuously until after the vessel's arrival in Boston.[33] (See table 1.) After the accident, Majesty Cruise Line advised the Safety Board that the anomalous 197°/000° courses recorded by the bell log were the result of the GPS receiver being in the SOL and DR modes.

The bell log also recorded speed calculations based on information provided by the GPS. The bell log recorded 18 speed calculations between 1200 on June 9 (departure time from the pier) and 2000 on June 10. These speed calculations and the time at which they were recorded are listed in table 2. The *Royal Majesty*'s watch officers also maintained written records of the vessel's speed during the voyage in the bridge log and in the speed record. According to entries made in the bridge log between 1400 on June 9 and 1200 on June 10, the vessel's average speed was 19.06 knots. The bridge-log speed data, however, were calculated using position data from the GPS. If the GPS was in DR mode, the bridge-log speed data would not account for wind, seas, and current. The speed data recorded by watchstanders in the speed record were based on distances between DR positions shown on the GPS. The distances between DR positions depended on the speed supplied by the Doppler speed log.[34] The speed data, which were recorded at hourly intervals between 1500 on June 9 and 2200 on June 10, indicated that between 1400 on June 9 and 2200 on June 10 the vessel's average speed was 18.79 knots. The speed record also showed that between 1200 and 2200 on the day of the accident, the vessel's average speed was 13.87 knots.

[31]Mean solar time in which the day begins at midnight on the meridian of Greenwich. For this report, the entry times have been converted to local time.

[32]During this time, the *Royal Majesty* was moored with its port side to the Ordnance Island Passenger Terminal in St. George's.

[33]The *Royal Majesty*'s bridge logs indicated that the vessel departed the Ordnance Island Passenger Terminal at 1203, dropped off its pilot at 1230, and then altered course to 059°. Shortly before 1300, the vessel altered course to 336° and remained within 1° to 3° of this heading until the grounding.

[34]The Doppler speed log provided watchstanders with a digital readout of the vessel's speed (over ground) at any given moment in time. The readout did account for wind, sea, and current.

Table 1—Bell-log record of courses, June 9, 1995 (based on data from the GPS unit)

Time	Course Made Good	Time	Course Made Good	Time	Course Made Good	Time	Course Made Good
1131:54	(GPS unit turned on)	(continued from previous column)		(continued from previous column)		(continued from previous column)	
1132:46	**197.0**	1147:11	094.0	1201:35	210.0	**1321:59**	**0**
1133:01	**0**	1147:59	115.0	1201:52	203.0	**1322:47**	**197.0**
1133:17	**197.0**	1149:35	159.0	1202:07	212.0	**1324:41**	**0**
1137:17	291.0	1150:07	129.0	1202:40	206.0	**1324:55**	**197.0**
1138:05	275.0	1150:23	181.0	1203:11	213.0	**1332:57**	**0**
1138:21	258.0	1150:55	064.0	1204:15	169.0	**1333:45**	**197.0**
1138:37	306.0	1151:11	097.0	1205:51	091.0	**1349:29**	**0**
1139:09	215.0	1151:59	0	1206:23	097.0	**1349:45**	**197.0**
1139:25	250.0	1152:15	047.0	1206:55	088.0	**1357:45**	**0**
1139:41	232.0	1152:31	078.0	1211:11	082.0	**1358:07**	**197.0**
1139:57	250.0	1152:47	131.0	1219:12	090.0	**1406:01**	**0**
1140:13	261.0	1153:19	092.0	1219:27	082.0	**1406:33**	**197.0**[a]
1141:01	038.0	1153:35	151.0	1228:32	076.0		
1141:17	242.0	1153:51	133.0	1229:19	070.0		
1141:49	298.0	1154:55	174.0	1230:09	064.0		
1142:07	326.0	1155:11	130.0	1242:41	055.0		
1142:23	345.0	1155:43	213.0	1244:33	037.0		
1142:39	289.0	1155:59	320.0	1245:37	025.0		
1143:41	074.0	1156:15	271.0	**1252:02**	**197.0**		
1144:31	025.0	1156:31	261.0	**1255:45**	**0**		
1145:03	100.0	1156:47	217.0	**1256:01**	**197.0**		
1145:19	079.0	1157:03	227.0	**1304:01**	**0**		
1145:35	068.0	1157:19	208.0	**1305:05**	**197.0**		
1146:07	080.0	1158:39	216.0	**1309:06**	**336.0**		
1146:33	008.0	1200:04	221.0	**1311:46**	**197.0**		

[a] The bell log continued to record the 197º/000º headings until after the vessel’s arrival in Boston.

The *Royal Majesty* was also fitted with an Atlas 481 echo sounder (fathometer)[35] with digital readout. The fathometer data could be displayed on the NACOS screen by pressing a button. The fathometer had a recorder, which was in the chart room. Postaccident examination of the fathometer recorder indicated that it was not turned on at the time of the accident.[36]

The fathometer was also fitted with alarms that were activated whenever the vessel transited waters shallower than the water for which the alarms were set. In addition to an aural alarm, a flashing message appeared on the NACOS display. Both the aural alarm and the flashing message could be overridden by watchstanders.

[35] An echo sounder, or electronic depth sounder, is an instrument that indicates water depth below the bottom hull plating. Hereinafter, the term *fathometer* will be used in the report.

[36] The chief officer, the navigator, and the second officer testified that the echo sounder was turned on before the accident. The recorder had a separate on/off button.

Table 2—Bell-log record of the speed calculations based on information obtained from the GPS unit

June 9, 1995		June 10, 1995	
Time	**Speed (Knots)**	**Time**	**Speed (Knots)**
1200:03	13.3	0000:03	12.7
1206:39	14.7	0400:03	12.7
1210:23	16.0	0800:03	12.7
1223:43	17.3	1200:03	12.7
1225:03	18.8	1600:03	12.7
1228:31	21.1	2000:04	12.7[a]
1233:19	22.3		
1252:01	12.7		
1309:05	21.3		
1311:45	12.7		
1600:03	12.7		
2000:04	12.7		

[a] The bell-logger printout continued to record a speed made good of 12.7 knots from 2000 (June 10) up to the time of the vessel's arrival in Boston on June 12.

The chief officer and the navigator testified that the fathometer alarm was normally set to go off when the water beneath the keel was less than 3 meters (9.75 feet) deep. On the night of the grounding, the *Royal Majesty*'s deep draft was 19 feet 6 inches. Based on statements from the chief officer and the navigator, the alarm should have activated when the *Royal Majesty* entered water with a depth of 29 feet 4 inches or less. During the hour preceding the grounding, the *Royal Majesty* passed over Great Rip and Davis Shoals, where in some areas the depth of the water was less than 29 feet 4 inches. The master, chief officer, and second officer did not recall seeing or hearing the fathometer alarm before the grounding. Postaccident examination revealed that the fathometer alarm was set at 0 meters. According to the navigator, the alarm was normally set at 0 when the vessel was in port or in a harbor to prevent the alarm from being continuously activated.

Crew Training on Integrated Bridge System.—The *Royal Majesty* entered service in June 1992. The master, who joined the vessel in November of that year, stated that before joining the vessel, he had read all the manuals and technical documents related to the integrated bridge system (see next section). He stayed aboard the ship for 1 month with the master he was relieving and received on-the-job training related to the integrated bridge system from that master and the navigator who was aboard the vessel when it entered service.

The chief officer of the *Royal Majesty* had joined the ship in 1992. He stated that he had also received on-the-job training (3 weeks) from the same navigator as the master had.

The navigator who was aboard the *Royal Majesty* at the time of the accident had joined the ship in August 1994. According to him, he was responsible for the orientation and training of new officers in the operation of the NACOS 25, GPS, Loran-C, Decca, fathometer, gyro(s), speed log, ARPA radars, and engine controls. He stated that he was solely responsible for programming the radar maps onto the ARPA display. He stated that it was his responsibility to ensure that watch officers fully understood how the different systems worked and interacted with each other. He further stated that one of his responsibilities was to tell the master when a newly assigned watch officer was fully prepared to stand a bridge watch alone. The navigator stated that the master made the final decision about whether an individual was sufficiently qualified to operate the bridge equipment and was fully conversant in the ship's watchstanding procedures.

The second officer joined the *Royal Majesty* on May 1, 1995. He received 3 weeks of on-the-job training—2 weeks with the navigator and 1 week with the chief officer. According to his testimony, the 3 weeks of on-the-job training included his being familiarized with the components of the integrated bridge system but also with other bridge watchstanding duties and responsibilities, fire and boat drills, vessel maintenance, and various other officer duties and responsibilities.

According to the testimony of the watch officers, there was no formal classroom or simulator-based training on the integrated bridge system, nor was any curriculum, checklist, or exam used during the 3 weeks of on-the-job training to measure the extent of the trainee's knowledge of the system or its components.

According to STN Atlas, the manufacturer of the NACOS 25, STN Atlas offers classroom and simulator training in the operation of its equipment at an additional cost to the purchaser. STN Atlas also indicated that several companies and organizations in Europe were qualified to provide formal classroom and simulator-based training in the operation of the STN Atlas NACOS 25. Majesty Cruise Line did not obtain such training from STN Atlas or any other organization, nor was it required to by any international regulations or standards.

Written Guidance on Use of the NACOS 25.—STN Atlas supplied several supporting manuals with the NACOS 25 on the *Royal Majesty*. Manuals for the Atlas NACOS 25 system included *Specifications*, *Navigation Instructions*, "Brief Navigation Instructions," *Operating Instructions*, and "Brief Operating Instructions."[37] In addition, STN Atlas provided manuals for the Atlas 8600 ARPA radar and the programming of maps using the ARPA radar. STN Atlas notes the following in its concluding remarks in the *Navigation Instructions*:

> The navigator's role is that of overseer of the ship's progress and proper functioning of the automatic equipment. If the system performs faultlessly, it could happen that the navigator loses interest in overseeing a faultlessly functioning system. Before entering into this situation one must set about planning the next stage of development.
>
> In the next stage of development, one must consider changing the automation so that the supervising of the navigation will be done automatically instead of by the navigator.

Waterway Information

The *Royal Majesty* grounded on Rose and Crown Shoal about 10 miles east of Sankaty Head Light, which is on the eastern shore of Nantucket Island and about 17.0 miles west of the vessel's intended track (the northbound Boston traffic lane). The shoal extends approximately 5 miles in a north-south direction and about 3 miles in an east-west direction. The minimum depth of the water in this area ranges between 3 and 7 feet at mean low water. The area is also known to contain breakers. The shoal is marked by a lighted whistle buoy (2RC). The buoy's red light flashes at 2.5-second intervals and is visible at a distance of at least 6 miles when visibility is clear.

Rose and Crown Shoal is one of several broken shoals that compose Nantucket Shoals—the general name of the shoals that extend 23 miles east and 40 miles south of Nantucket Island. The currents in this area are strong and erratic, reaching a velocity of 3 to 5 knots around the edges of the shoals. According to Volume 2 of *U.S. Coast Pilots (Atlantic Coast: Cape Cod to Sandy Hook)*, Nantucket Shoals is "one of the most dangerous parts of the coast of the United States." It also states that "this area should be entirely avoided by deep draft vessels when possible and by light draft vessels without local knowledge."

The shoals, which are shifting in nature, are bordered to the south and east by several aids to navigation. The southwest corner of Nantucket Shoals is marked by the Davis South Shoal lighted whistle buoy. The buoy has a red light that flashes at 4-second intervals and is visible at a distance of about 4 miles when visibility is clear. Marking the southeast corner of Nantucket Shoals is the Asia Rip (AR) lighted bell buoy. This buoy, which is about 17 miles west of the *Royal Majesty*'s intended track and 15 miles (on a bearing of 248°) away from the BA buoy, has a yellow light that flashes at 2.5-

[37] The briefs were laminated two-page summaries of the larger manuals and were meant to be used as quick reference material.

second intervals. Fifteen miles to the south-southwest of the AR buoy and 30 miles west of the *Royal Majesty*'s intended track is the Nantucket Shoals lighted horn buoy. This buoy, which replaced the original Nantucket Lightship, is a large navigational buoy[38] that has a yellow light that is 40 feet above the water and flashes at 6-second intervals.

Large deep-draft vessels operating between Bermuda and Boston generally use the Boston traffic lanes east of Nantucket and Cape Cod. The purpose of the traffic lanes is to separate northbound and southbound vessels and to provide a deep-water route for vessels en route to and from Boston that keeps them clear of Nantucket Shoals. A traffic separation zone separates the northbound and southbound lanes. Marking the separation zone are a series of lighted buoys (BA, BB, BC, BD, BE, and BF). Each buoy has a flashing yellow light and a radar reflector and has a distinctive flashing characteristic. For example, the yellow light on the BA buoy, which marks the southeast entrance to the traffic lanes, flashes four times at 20-second intervals. The BA buoy also sounds a whistle at 10-second intervals when certain rough sea conditions exist.

Meteorological Information

The weather and sea conditions recorded by the *Royal Majesty* crew between 1800 and 2230 on June 10 generally indicated cloudy skies, force 4 winds[39] (between 11 and 16 knots) out of the east, and seas between 2 and 4 feet. Visibility at sea level was reported to be at least 10 miles.

A review of the bridge log for the 24-hour period beginning at 2100 on June 9 indicated that the *Royal Majesty* encountered winds averaging 15.9 knots out of the east-northeast. Based on the Beaufort scale, a 16-knot wind could generate a wind-driven current capable of setting the *Royal Majesty* toward the west-southwest at a rate of 0.32 knots, or a distance of about 8 miles over a 24-hour period. The effect of the wind on the vessel's vast superstructure would have also contributed to the vessel's westerly drift.

Toxicological Information

The Coast Guard does not have the authority to order postaccident toxicological testing in accidents on foreign vessels that occur in international waters.[40] However, Majesty Cruise Line requested that all watchstanders on the bridge at the time of the grounding and the master provide specimens for toxicological testing. The company tried to obtain the services of a testing firm that could travel to the site of the grounding. On the following day, June 11, the company found a contractor in New Hampshire who agreed to collect the specimens. He arrived on scene in a chartered fishing vessel and was transported to the *Royal Majesty* on a Coast Guard vessel about midnight. The Coast Guard requested that the contractor wait until it was safe to board, as the Coast Guard was still in the process of freeing the vessel. After boarding, he was directed to the office of the ship's doctor and began collecting the specimens soon thereafter.

Twenty-five to 28 hours after the grounding, the master, the second officer, and the two lookouts on duty at the time of the grounding gave blood and urine specimens for alcohol and drug testing specified in 46 *Code of Federal Regulations* (CFR) Part 4 and in 49 CFR Part 40. The specimens were shipped for testing to the Methodist Medical Center in Peoria, Illinois. The results of the tests were negative.

Watchstanding Policies and Practices

Three licensed deck officers and six unlicensed crewmen were assigned to the watchstanding duties aboard the *Royal Majesty*. Each stood a 4-hour-on/8-hour-off watch rotation. The watches for the three licensed deck officers were as follows:

[38] A 40-foot-diameter, automated disc-shaped buoy used to replace lightships. Most large navigational buoys are used in conjunction with major traffic separation schemes.

[39] Based on the Beaufort scale, a numerical scale from 0 to 12 that rates wind according to ascending velocities (*0* corresponds to calm winds at 0 to 1 knots, and *12* corresponds to hurricane winds above 65 knots).

[40] 33 CFR Chapter 1, Subpart 2.05-5.

0000-0400/1200-1600	Navigator
0400-0800/1600-2000	Chief Officer
0800-1200/2000-2400	Second Officer

The master of the *Royal Majesty*, who did not stand a regular watch, oversaw the performance of the watch officers. According to the master, in good weather he typically visited the bridge two to three times during the course of a watch and frequently telephoned the officer of the watch for navigation and traffic updates. He stated that he visited the bridge more frequently when the weather or sea conditions were bad or when visibility was poor.

Company policy governing the activities of the bridge watchstanders aboard the *Royal Majesty* are contained in its "Bridge Procedures Guide" and the Majesty Cruise Line's *Operations Manual*. The two-page "Bridge Procedures Guide" (see appendix B) was posted on the bridge of the *Royal Majesty* before the accident. According to Majesty Cruise Line, the purpose of the "Bridge Procedures Guide" is to provide watchstanders "with a description of the day-to-day bridge procedures that are recognized as good practice and to promote through them the safety of the M/V *Royal Majesty*, her passengers, and crew."

The *Operations Manual* contains a collection of policies, letters, and circulars covering such topics as checking the vessel's position, fire and boat drills, and payroll and accounting procedures. Duties of the officer on watch are listed on page 3 of Majesty Cruise Line's Circular No. 9, dated July 9, 1992 (see appendix C). The circular states that deck watch officers are to "check the ship's position as often as conditions and circumstances allow, but never longer than 30-minute intervals." The circular does not state how the ship's position is to be checked, nor does it require that GPS and Loran-C position data be compared. The circular also does not require that a written record be maintained of GPS or Loran-C observations or of radar ranges and bearings of nearby floating aids to navigation and/or landmarks.

The master testified that he required his watch officers to plot the vessel's position on an hourly basis. A postaccident examination of National Oceanic and Atmospheric Administration chart No. 13200 (*Georges Bank and Nantucket Shoals*) indicated that hourly fixes had been plotted on the chart of the area starting about 100 miles to the south of the accident site and continuing up into the Boston traffic lanes.

Circular No. 9 and the "Bridge Procedures Guide" discuss when the master should be summoned to the bridge. Among the circumstances that should prompt a call to the master is the failure of watch officers to sight land or a navigation mark or to obtain a sounding by the expected time.

Postaccident Testing of GPS

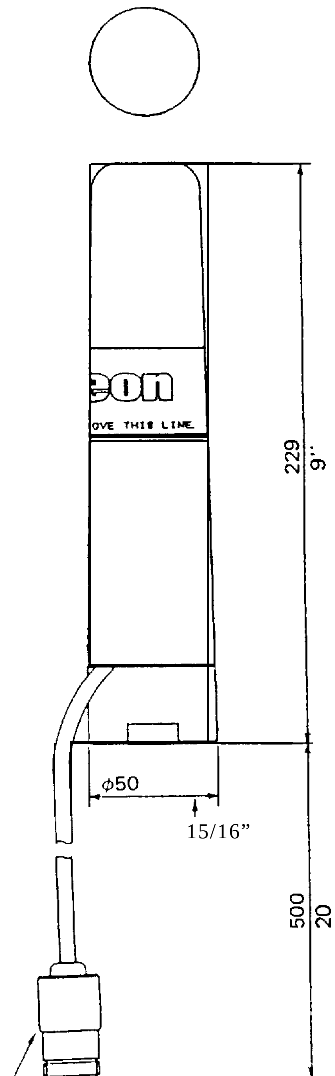
After the accident, representatives from Majesty Cruise Line and the Coast Guard examined the *Royal Majesty*'s GPS antenna and receiver. They found that the GPS antenna cable had separated from the factory connection at the antenna. The antenna cable, which was factory-assembled, showed no sign of physical damage, other than having been separated from the connection. The Safety Board examination also revealed that the cable was openly routed on the roof of the bridge and that it had been painted with a brush or roller at least twice when the bridge was being painted (see figure 9). Traffic on the roof of the bridge was limited to Majesty Cruise Line employees. However, the GPS cable was not secured to the roof or protected from someone tripping over it, kicking it, or otherwise damaging it and the nearby antenna connector.

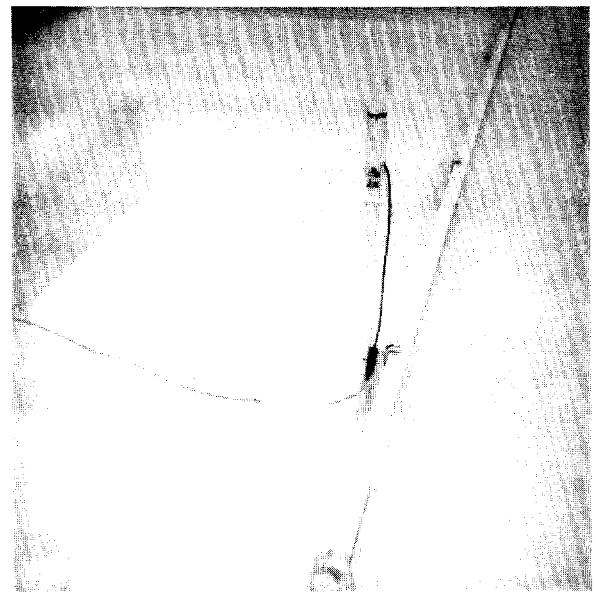
Postaccident testing at Raytheon[41] indicated that because the GPS antenna cable was separated from the connection, the GPS receiver transmitted DR-derived position data instead of satellite-derived position data to the NACOS 25 autopilot.

Safety Board's Urgent Safety Recommendations

The Safety Board's postaccident testing and inspection of the integrated bridge system on the

[41] Appendix D has more details about the postaccident testing done by representatives of the Safety Board, Raytheon Marine, and Majesty Cruise Lines.





GPS antenna and cabling as installed on deck of Royal Majesty fly bridge

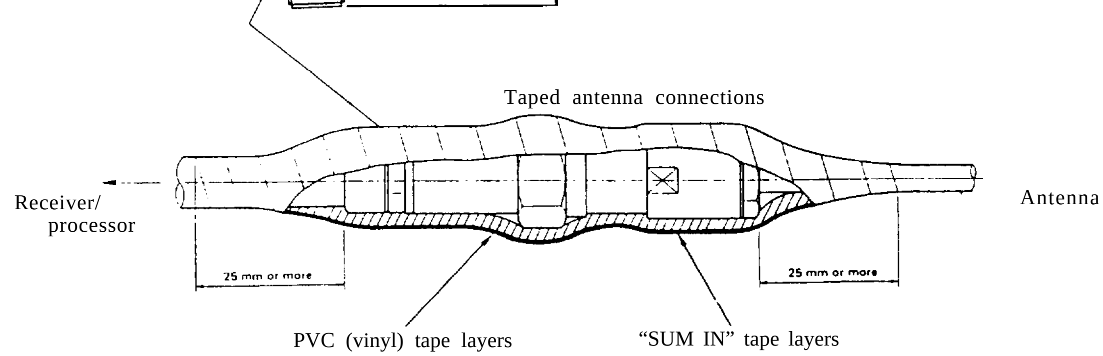


Figure 9—GPS antenna assembly (photograph shows antenna and cabling as installed on deck of fly bridge). .

Royal Majesty raised concerns about the safety of the world's maritime fleet and the safety of passengers and crews on vessels with similar integrated bridge systems, as well as the potential damage to the environment that could result from a release of hazardous cargo. Consequently, on August 9, 1995, the Safety Board issued five urgent safety recommendations to the Coast Guard, the International Council of Cruise Lines (ICCL), the International Chamber of Shipping, the American Institute of Merchant Shipping, the International Association of Independent Tanker Owners (INTERTANKO), STN Atlas, and the NMEA. The recommendations urged the organizations to immediately advise maritime vessel operators of the circumstances of the Royal Majesty's grounding and to encourage the operators to review the design of their integrated bridge systems to identify potential system and operational failure modes. All five recommendations were acted upon and, consequently, have been classified either "Closed—Acceptable Action" or "Closed—Acceptable Alternate Action."42

Safety Board's Public Forum

The grounding of the *Royal Majest*y suggested to the Safety Board a need to assess the current state of the art in integrated bridge systems. As a first step, the Safety Board held a public forum on integrated bridge systems on March 6-7, 1996, to examine data-transmission standards, design standards for integrated bridge systems, human-factors considerations in the design of integrated bridge systems, training and certification of mariners responsible for operating integrated bridge systems, and the impact of integrated bridge systems on safety, workload, and watchkeeping. Participating in the public forum were representatives of the vessel operators, standards organizations, manufacturers of integrated bridge systems, and classification societies. Government representatives and marine educators from the major maritime schools, colleges, and universities also participated.

The following sections highlight some of the comments from the various participants.

Manufacturers.—The public forum showed that manufacturers of integrated bridge systems are designing and building the components of their systems in accordance with internationally recognized standards, proprietary standards, and the standards of the classification societies. Manufacturers stated that problems were occasionally encountered in matching subsystems, such as Loran-C and GPS, speed logs, and gyro compasses, with the integrated bridge system that they manufacture. They expressed concern about the maintenance of system integrity throughout the life of the integrated system as subcomponents are added or replaced. They expressed the belief that an independent authority is needed to ensure system integrity.

Standards Organizations.—The International Maritime Organization (IMO), a United Nations organization, produces performance standards for navigation equipment required on commercial vessels. Such standards are normally cast in general terms. Once adopted, each of the IMO performance standards is reviewed by either Technical Committee 8 (TC8) of the International Standards Organization (ISO) or, more often, by Technical Committee 80 (TC80) of the IEC, depending upon whether the equipment is mechanical or electric/electronic. Normally, one of the two organizations will develop specifications (called standards) that enable manufacturers to design and build navigation equipment that will meet the appropriate IMO performance standard. It is not unusual for the ISO and the IEC to work jointly to produce standards.

The ISO and the IEC are parallel international organizations, working in close cooperation to form a world system of standardized working procedures, terminology, and documentation presentation. The TC8 has 10 subcommittees working on various areas, including

[42] Appendix E has the full text and status of each urgent safety recommendation.

ship bridge layout[43] for one-person watchkeeping.[44]

The work of the IEC is managed through more than 200 technical committees, and the TC80, formed in 1979, is the technical committee concerned with marine navigation and radiocommunication equipment and systems. The TC80 has 10 working groups.

In 1990, the TC80 notified the IMO that it was forming a working group (WG9) to develop a draft IMO performance standard for integrated bridge systems. The proposed standard was completed and submitted to the IMO in July 1996. The proposed standard is expected to become an IMO performance standard by about 1999.

In the absence of an ISO or IEC standard, manufacturers use other internationally recognized standards, such as those of the NMEA. The NMEA, a U.S. organization of manufacturers, dealers, and installers of marine electronic equipment, actively encourages international membership and participation. The NMEA Interface Standards Committee, for example, has representatives from nearly all the companies in the world that manufacture marine electronic equipment.

The NMEA and the IEC have members on each other's working groups and in 1995 collaborated to produce a harmonized standard for data transmission (NMEA 0183 and IEC 1162-1), which will facilitate matching subsystems like GPS with integrated bridge systems and the Global Maritime Distress and Safety System.[45] The NMEA and the IEC have agreed to work together on future transmission standards and to keep both standards in harmony.

The NMEA representative stated that manufacturers have sometimes made different interpretations of the NMEA standards and that electronic equipment has been mismatched. The NMEA representative further stated that the 0183 standard by itself does not regulate the use of the data in NMEA-provided sentences. The NMEA counts on the knowledgeable input to, and sensible implementation of, the NMEA standard by equipment designers. This process has improved vastly over the past few years and many of the early problems with implementation no longer exist. Helping in this regard is the trend in international performance standards for marine electronic equipment to specify the use of specific NMEA 0183/IEC 1162-1 sentences. The representative stated that he believes that the new improved standards have reduced the possibility of mismatching.

Classification Societies.**—**The DNV has been involved in bridge navigation issues since the early 1970s; the classification society was motivated to enter this nontraditional area by the high number of groundings and collisions attributable to human error. The DNV studied the bridge environment, including design of work stations, organizational matters, range and quality of instrumentation, and man/machine interface. The DNV then developed some standards for bridge design and equipment that might reduce situation-induced errors. These standards were offered as an optional classification notation,[46] NAUT-C.

[43]ISO standard ISO 8468 currently covers ship bridge design and layout.

[44]One-person watchkeeping, sometimes referred to as one-man or solo watchkeeping, means that the officer of the watch is the sole person on the bridge. This concept envisages reducing cost by eliminating the lookout position from the navigation watch.

[45]The Global Maritime Distress and Safety System is an automated radio transmitting and receiving device on the bridge. It can automatically send distress messages that give the vessel's identification and position and receive telex information on navigation, weather, and search and rescue.

[46]Classification societies have normally been concerned solely with developing classification rules (notations) for a vessel's hull, the machinery, and certain essential systems (ballast systems, piping, sanitation systems, ventilation, etc.). For a vessel to be classed by a society, the vessel must be constructed and maintained in accordance with the rules of the classification society. Surveyors (inspectors) employed by the selected classification society inspect the vessel during construction and periodically afterward as long as the vessel is classed. Classification is essential for obtaining insurance. Navigation equipment is not required to be classed; thus, the navigation bridge does not have to be constructed or outfitted in accordance with classification society rules. With growing interest in reducing navigation errors and with the interest in using technology to reduce bridge manning, most classification societies now offer optional classification rules (nota-

Currently, the highest class notation offered by the DNV is *Watch 1* (W1), which addresses equipment requirements, qualifications of the integrated bridge system operator, operating procedures, documentation on maneuvering performance, and a contingency plan. The DNV requires that vessel officers attend classes provided by the integrated bridge system manufacturer. An officer who has been trained by the manufacturer and has operated an integrated bridge system at sea may instruct other officers. All operators of an integrated bridge system must be certified by the DNV.

Germanischer Lloyd was the coordinator for the German Ship of the Future program, which involved various elements of the German maritime industry. The intention of this research program was to employ automatic navigation systems to do routine functions; as a result, watchkeeping at any time, day or night, could be handled by one person. The culmination of the Ship of the Future program was marked in 1985 by the commissioning of a prototype vessel with an integrated bridge system. In 1991, Germanischer Lloyd published its *Rules for Bridge Design on Sea-Going Ships - One-man Control Console*. The rules were based on 5 years of operational experience with advanced navigation systems. A ship complying with the rules receives the optional class notation *Nav O* (ocean area) or *Nav OC* (ocean area/coastal waters).

Lloyd's Register of Shipping (LR) published rules for navigation bridge arrangements in 1988 and in January 1996, after completing further research, replaced those rules with a more comprehensive notation (*NAV-1*).[47] The LR is planning to offer an integrated bridge system notation, *IBS*, which will be an enhancement of NAV-1. The notation also will address software, and will require that the "development, modification, replication and installation of the software be subject to quality plans which meet the requirements of acceptable standards, e.g. the ISO 9000 series." The LR will accept certification of the software quality procedures by a recognized authority as evidence of compliance. Also, the LR can now provide comprehensive software assessment to manufacturers. (The DNV tests software at the manufacturer's plant for each model of an integrated bridge system and whenever there are changes in software.)

Nippon Kaiji Kyoukai published rules for navigation bridge systems in February 1995. In preparing the rules, the organization considered current Japanese technology, other technical developments, vessel-owner desires, and international standards, including those of the IMO, the ISO, and the IEC.

The Nippon Kaiji Kyoukai notation *BRS1* covers "functionality of the bridge design layout, configuration, bridge environment, and essential navigational equipment to be installed and work stations for one officer bridge operation on the open sea."

The Korean Registry of Shipping has introduced requirements for one-man bridge operated ships. In developing its rules, the organization gave a high priority to the safety and reliability of systems. The organization also focused on the human element, including ergonomic criteria and bridge design and installation, as well as on technical performance standards, system redundancy, and reliability.

The American Bureau of Shipping published guidelines for one-man bridge operation in 1992.

tions) covering bridge design, layout, and equipment.

[47]The development of NAV-1 followed a 3-year research project known in Europe as Advanced Technology to Optimize Manpower Onboard Ships. The object of the project was to improve the competitiveness of European Common Market commercial vessels by using advanced technology, including the integration of bridge equipment and functions, to reduce bridge manning and contribute to navigation safety. The participants in the research project included nine European companies and, in addition to the LR, equipment manufacturers, ship owners, research organizations, and one national authority.

ANALYSIS

General

The weather at the time of the accident was clear, visibility was at least 10 miles, seas were calm, and winds were light. Except for the GPS antenna cable connection, all other navigation equipment and the main propulsion, steering, and auxiliary systems were fully operational before and after the accident. The investigation indicated that the certifications of the master and the deck officers were in accordance with current international requirements. Accordingly, the Safety Board concludes that the weather, the mechanical condition of the *Royal Majesty*, except for the GPS antenna cable, and the officers' certifications were not factors in the accident.

Because the accident happened in international waters, the Coast Guard did not have the authority to order toxicological testing. However, the master, the second officer, and the two lookouts on duty at the time of the accident provided blood and urine specimens for alcohol and drug testing, as requested by Majesty Cruise Line. On the basis of test results, the Safety Board concludes that drugs were not a factor in the accident. However, because the specimens were obtained more than 24 hours after the accident, the alcohol tests were of little value; had there been any alcohol, it probably would have been metabolized and eliminated. Although investigating Coast Guard personnel observed no indications that the officers had been under the influence of alcohol, the Safety Board could not determine conclusively that alcohol was not a factor in the accident.

The master and two of the deck officers, including the second officer, who was on duty at the time of the accident, testified that their work/rest routines during the days preceding the accident were normal. In particular, the second officer slept about 7 hours after finishing his 2000-to-2400 watch and had also taken a 2-hour nap before beginning his 2000 watch on June 10, the day of the accident. In short, the Safety Board concludes that fatigue was not a factor in the grounding of the *Royal Majesty*.

The Safety Board assessed the fishing vessel's attempts to call a cruise ship shortly before the grounding of the *Royal Majesty*. Although the Safety Board could not conclusively determine whether the second officer was in fact monitoring channel 16, international requirements and company procedures required him to do so. Because the position transmitted by the fishing vessel was approximately 17 miles away from where the second officer believed the vessel to be and because the English transmissions made by the fishing vessel to the cruise ship did not convey any urgency or immediacy and were interspersed with Portuguese conversation, the Safety Board believes it was reasonable that the second officer did not respond to these transmissions. The transmissions do, however, provide evidence of the location of the *Royal Majesty* almost 2 hours before the grounding.

The grounding occurred near Nantucket Island in an area known as Rose and Crown Shoal—a location more than 17 miles west of the vessel's intended track. The investigation, therefore, focused on determining how a large passenger vessel with a sophisticated integrated bridge system, manned by experienced watch officers, and operated in clear weather through calm seas could travel, unknown to the crew, more than 17 miles off course.

The Accident

Shortly after the vessel left St. George's, the navigator set the NACOS 25 autopilot on the NAV mode. When engaged and operating in the NAV mode, the autopilot could steer the vessel along a predetermined route using programmed information (latitude and longitude of waypoints and the vessel's maneuvering characteristics), gyro and speed data, and position data from either the GPS or the Loran-C while automatically compensating for the effect of gyro error, wind, current, and sea. On the day of the accident, the crew had selected, as it normally had done since the vessel entered service, the GPS as the source of position data for the NACOS 25.

To compensate for the possible lack of satellite data, the GPS unit on the *Royal Majesty* had been designed to receive speed and gyro heading data so that when GPS satellite data were not available, the unit would automatically default to a DR mode, in which the latitude/longitude data transmitted to the autopilot were derived from DR calculations rather than satellite-based position data. When the GPS unit defaulted to the DR mode after the vessel left Bermuda, the autopilot was unable to recognize the status change; and, thus, its subsequent navigation did not correct for the effect of wind, current, or sea.

The bell-log record provided evidence that complete interruption of valid satellite-based position data occurred about 1311:46, which was about an hour after the vessel left St. George's. From that point on, the bell log continued to record alternate courses of 197° and 000° until after the vessel's arrival in Boston, although, in fact, the vessel was maintaining a course of about 336° during that time. It appeared that a temporary interruption of valid satellite-based data occurred at 1252:02, about 52 minutes after the vessel left Bermuda, as the course and speed recorded were 197° and 12.7 knots, respectively—the same readings that were later recorded. The course of 336° recorded at 1309:06 was consistent with the vessel's course at that time. Similarly, the bell-log record of speed calculations based on the data provided by the GPS unit indicated that the last accurate recording occurred at 1309:05 when the bell log recorded a speed of 21.3 knots. However, from that point on until the vessel's arrival in Boston on June 12, the bell log continued to record a speed of 12.7 knots, a speed not consistent with the speeds recorded in the bridge log and speed record. In summary, the Safety Board concludes that starting about 52 minutes after the *Royal Majesty* left St. George's, the GPS receiver antenna cable connection had separated enough that the GPS switched to DR mode, and the autopilot, not programmed to detect the mode change and invalid status bits, no longer corrected for the effects of wind, current, or sea. Over time, the effects of the east-northeasterly wind and sea set the *Royal Majesty* in a west-southwesterly direction and away from its intended track, resulting in the 17-mile error. Further evidence came from a Coast Guard transcript of radio transmissions from two fishing vessels that were in the vicinity of Fishing Rip Shoal on the evening of June 10 and had seen a large passenger cruise ship about 16 miles west of the Boston traffic lanes.

The investigation determined that the GPS antenna, which was originally installed on the radar mast, had been moved in February 1995, several months before the grounding, as part of an effort to eliminate chopping. An examination of the GPS antenna cable indicated that it was routed in such a way that it could be kicked or tripped over, which could induce separating stress at the antenna cable connection, and that it had been painted on at least two occasions. However, precisely when the painting was done was not known. In short, it could not be determined whether the GPS antenna failed as a result of crewmembers' inadvertently damaging it while they were doing routine maintenance, as a result of crewmembers' tripping over the cable, or as a result of other unknown factors. Nevertheless, the Safety Board concludes that openly routing the GPS antenna cable in an area where someone occasionally walked increased the risk of damage to the cable and related connectors. The Safety Board believes, therefore, that to decrease the risk of damage, Majesty Cruise Line should eliminate the practice of openly routing navigation equipment cable to decrease the risk of damage and that the ICCL should encourage its members to do the same.

Watch Officers' Performance

The crew's failure to detect the ship's errant navigation for more than 34 hours raises serious concerns about the performance of the watch officers and the master. None of the three watch officers or the master determined that the GPS had switched to DR mode or that the *Royal Majesty* had been on an errant course throughout the trip from St. George's. Further, the chief officer and the second officer, who stood the last two watches before the grounding, failed to recognize that the *Royal Majesty* was on an errant course despite several indications that the vessel was not on its intended track. The investigation, therefore, examined the events leading up to the accident from the time the *Royal Majesty* departed St. George's, including the inspecting of equipment and the setting of the fathometer alarm. The investigation also examined the watchstanding practices of the watch officers and their lack of response to several indications that the vessel was not following its intended track, including the sighting of red lights, the failure to sight the BB buoy, and the sighting of blue and white water.

Equipment Inspection.—The navigator said that he had tested the navigational equipment before the vessel left St. George's and found the equipment to be in "perfect" operating condition. Because the evidence from the bell log indicated that interruption of GPS data did not occur until about 1252, about an hour after the vessel had left port, the GPS receiver would probably not have shown the *SOL* and *DR* messages before that time. Consequently, the navigator may indeed have inspected the GPS receiver before the departure when the other navigation equipment was inspected and found no anomalies.

Fathometer Alarm.—Although the testimony indicated that the fathometer alarm was usually set at 3 meters, the postacccident investigation determined that the fathometer alarm was set at 0 meters—the setting used when the vessel was in port or in harbor so that the alarm would not be continuously activated. During the voyage, no one detected that the fathometer setting was improper, and the fathometer recorder was not turned on. Because the fathometer alarm was set at 0 meters, the aural fathometer alarm would not have activated; thus, the setting effectively rendered the alarm useless.

Before it grounded, the *Royal Majesty* passed over several areas in which the depth of water beneath the keel was significantly less than 3 meters. Had the alarm been set as usual to 3 meters, it would have activated several times before the vessel grounded. The Safety Board concludes that had the fathometer alarm been set to 3 meters, as was the stated practice, or had the second officer chosen to display the fathometer data on the control console, he would have been alerted in time for him to take corrective action that the *Royal Majesty* was in far shallower water than expected and, thus, was off course. Because of the proximity of Davis Bank (a shoal about 8 miles southeast of the grounding site; the water is between 15 and 40 feet deep) it is possible that he would have been alerted perhaps as long as 40 minutes before the grounding.

GPS Status.—Once the ship had been placed under the control of the automated navigation system, the watch officers' operating tasks were to ensure that the automated navigation system equipment was operating properly and to verify that the *Royal Majesty* was following the intended track. The testimony of the watch officers and the charts used by these officers indicated that hourly fixes were being plotted during the voyage, as instructed by the master. The navigator and the second officer both testified that the hourly fixes they plotted were based on position data from the vessel's GPS. However, according to testimony, no officer, including the master, recognized the *SOL* and *DR* messages, indicating that the GPS position data were not reliable, until after the grounding. Because the crew noticed the *SOL* and *DR* messages immediately after the grounding and because postaccident testing confirmed that the *SOL* and *DR* messages were functioning properly and should have been displayed, the watch officers apparently read the position coordinates on the GPS unit to accomplish their manual plotting task, without attending to the *SOL* and *DR* messages. The Safety Board concludes that the watch officers' monitoring of the status of the vessel's GPS was deficient throughout the voyage from St. George's.

Cross-checking of Position Data.—Despite failing to recognize the *SOL* and *DR* indicators, the officers could have discovered that the GPS had defaulted to DR mode by using an independent source of information, such as the Loran-C. According to the chief officer and the navigator, they periodically compared the GPS data with the Loran-C data during the voyage. The second officer, however, stated that he did not check the Loran-C because it was used as a backup only if the GPS failed. At the site of the grounding, the Loran-C indicated the correct position of the *Royal Majesty*, and there was no evidence that the Loran-C was malfunctioning during the voyage. Thus, had the officers regularly compared position information from the GPS and the Loran-C, they should not have missed the discrepant coordinates, particularly as the vessel progressed farther from its intended track. The Safety Board concludes that deliberate cross checking between the GPS and the Loran-C to verify the vessel's position was not being performed and should have been on the voyage from St. George's.

Use of Position-fix Alarm.—Evidence suggested that instead of monitoring the position instrumentation, the watch officers relied on the position-fix alarm, a feature of the autopilot designed to alert watchstanders to any degradation of position data from the position sensor in use. According to the officers, the only times the GPS positions could not be depended on for accuracy were during chopping episodes, which could usually be recognized because they were accompanied by an erratic movement of the radar map and the sounding of the position-fix alarm. Because chopping did not occur on the accident voyage and because the position-fix alarm never activated, the crew probably believed there was no need to suspect that the GPS was not providing satellite-derived position data. On this voyage, the position-fix alarm was set to activate only when the position data generated by the GPS and the DR position data generated by the autopilot differed by more than 200 meters. Because the GPS and autopilot shared common gyro and speed inputs, the DR position data transmitted by the GPS when it defaulted to the DR mode was essentially identical to the DR position data calculated by the autopilot. Consequently, the position-fix alarm would not have activated after the GPS defaulted to the DR mode. The Safety Board concludes that even though it is likely that the watch officers were not aware of the inherent limitation in using the position-fix alarm to monitor the accuracy of GPS position data, it was inappropriate for them to rely solely on the alarm to warn them of any problems with the GPS data.

Identification of Navigation Aids.—Although the officers' inadequate monitoring led to the errant track and was a serious deviation from acceptable methods of operating automated equipment, the grounding itself could have been avoided had the chief officer and the second officer followed longstanding good watchkeeping practices when approaching land. During the 1600-to-2000 watch preceding the accident, the chief officer did not visually identify the buoy he saw on the radar about 1900 and apparently assumed that it was the BA buoy, which marked the entrance to the traffic lanes. The target that he probably observed was the AR buoy, which marked a wreck about 17 miles west of the traffic lanes, and it was probably coincidental that he detected it when and where he anticipated seeing the BA buoy. He later explained that he was not concerned about confirming that the target was the BA buoy because the information displayed at the time on the GPS and ARPA displays indicated to him that confirmation was not necessary.

When the second officer assumed the following watch, he did not detect, either visually or by radar, the next buoy in the traffic lanes, the BB buoy, when it was expected. Contrary to standing orders from the master, he failed to report that he had not seen the BB buoy; and when the master called the bridge anticipating passing the buoy, the second officer stated that he had observed it.

The second officer continued to miss opportunities to avoid the grounding when the lookouts reported sighting several high red lights (later determined to be on Nantucket Island), sighting a flashing red light on the port bow, and sighting blue and white water ahead of the *Royal Majesty*. He acknowledged these observations, but he failed to take any action.

The second officer's response to these sightings should have been deliberate and straightforward. He should have been concerned as soon as the BB buoy was not sighted and then again when the lookouts sighted the red lights. Had he then increased the radar range from 6 miles to 12 miles on the port radar, the one radar in use, or turned on the starboard radar and set it to the 12-mile range, he would have detected Nantucket Island. He would also have seen that the radar pictures did not conform to the radar maps exhibited on the ARPA display. In addition, had he checked a chart of the area for the source of the flashing red light, he would have learned that the nearest flashing red light was the Rose and Crown Shoal buoy and, thus, would have been warned that the ship was not in the traffic lanes, as he believed it was.

Additionally, the second officer should have checked the Loran-C to cross check his position, as he knew the Loran-C to be accurate in this area. Had he still been uncertain about the position of the *Royal Majesty* after checking the Loran-C, he should have called the master and the navigator to the bridge for assistance. The Safety Board concludes that the sighting of lights not normally observed in this area and the second officer's inability to confirm the presence of the BB buoy should have taken precedence over the automation display on the central console and compelled the second officer to promptly use all available means to verify his position.

Fundamental seamanship practices caution against exclusive reliance on any one source of position information for navigation. When a watch officer finds visually sighted navigation aids that conflict with a position determined by automated instrumentation, he should promptly verify the vessel's position by using proper procedures. The Safety Board concludes that the chief officer and the second officer did not observe good watchkeeping practices or act with heightened awareness of the precautions that are needed when a vessel approaches the Boston traffic lanes and landfall. Consequently, in view of the actions of the watch officers on the *Royal Majesty*, the Safety Board believes that Majesty Cruise Line should review and revise as necessary the bridge watchstanding practices on all its vessels to ensure that all watch officers adhere to sound watchstanding practices and procedures, including using landmarks, soundings, and navigational aids to verify a vessel's position, relying on more than one source for position information, and reporting to the master any failure to detect important navigational aids. The Safety Board believes that the ICCL should encourage its members to take the same steps. The Safety Board further believes that Majesty Cruise Line and the members of the ICCL should periodically review the performance of all officers on board their vessels.

Master's Monitoring of the Vessel's Progress.—The investigation determined that the master of the *Royal Majesty* frequently visited the bridge to keep himself informed about bridge operations and to confirm that the passage was progressing satisfactorily. By requesting that the chief officer and the second officer report their sightings of the BA and BB buoys, the master made a reasonable effort to assure himself that the *Royal Majesty* was following its intended track. It is likely that the chief officer was not aware that he had misidentified the BA buoy, which marked the entrance to the traffic lanes, and unknowingly passed on erroneous information about the buoy to the master and the second officer. The second officer, however, deliberately misinformed the master when asked whether he had seen the BB buoy. Thus, the master was grossly misled by the second officer and was denied the opportunity to investigate clues indicating that the ship was not following the intended track.

The evidence suggests, however, that the master did not have any better understanding of the automated navigation system and the functioning of the GPS than the watch officers. His requirement that the officers plot courses manually did not result in anyone monitoring the vessel position by using an independent source of position information. Because the officers used the GPS data to get the coordinates for the manual plotting, the fixes on the chart corresponded with the map and positions displayed on the central console; thus the manual plotting in no way verified the validity of the GPS data. The master appeared to share the deck officers' reliance on the automated navigation system, since he did not ask for deliberate cross checks between the GPS and the Loran-C or make any comparisons himself. The Safety Board concludes that the master's methods for monitoring the progress of the voyage did not account for the technical capabilities and limitations of the automated equipment.

Effects of Automation on Watch Officers' Performance

Innovations in technology have led to the use of advanced automated systems on modern maritime vessels. However, bridge automation has also changed the role of the watch officer on the ship. The watch officer, who previously was active in obtaining information about the environment and used this information for controlling the ship, is now "out of the control loop." The watch officer is relegated to passively monitoring the status and performance of the automated systems. As a result of passive monitoring, the crewmembers of the *Royal Majesty* missed numerous opportunities to recognize that the GPS was transmitting in DR mode and that the ship had deviated from its intended track. The Safety Board examined why the watch officers missed the opportunities.

When the GPS unit defaulted to its DR mode, it displayed both *SOL* and *DR*, indicating that the GPS solution was no longer valid and that the unit had switched to a DR mode. Although the watch officers testified they used the GPS data for plotting, each officer also testified that he did not see *SOL* displayed on the GPS unit. Ineffective monitoring of sophisticated automated equipment is not new. The Safety Board has investigated several aviation accidents in which pilots failed to monitor flight instruments during automated flight.[48] Likewise, empirical research on the monitoring of automation has shown that humans are poor monitors of automated systems.[49] The problem of poor monitoring of automated systems was also known to STN Atlas, the manufacturer of the NACOS 25 system. STN Atlas warns in its operating manual for the NACOS 25 that operators, with little to do, may fail to monitor the automated NACOS 25 system.

The watch officers' failure to recognize the *SOL* or *DR* messages may also have been related to the absence of any loud alarm signifying poor GPS data. Before the separation of the antenna cable connection, failures of the GPS system triggered the NACOS 25 position-fix alarm. This could have led to what Wiener and Curry (1980) referred to as a primary/backup inversion.[50] The primary indicators of the status of the GPS unit are *SOL* and *DR*. As a backup to these primary indicators, the watch officers could use the position-fix alarm to signal inaccurate GPS data. As Wiener and Curry warned, the watch officers and the master of the *Royal Majesty* relied exclusively on the position-fix alarm instead of monitoring for *SOL* or *DR*. In 1988, the Safety Board investigated another case of primary/backup inversion in the crash of a Northwest Airlines Boeing 737 in Romulus, Michigan.[51] The plane crashed while the crew was attempting to take off in the wrong flight configuration. The crew apparently relied on an onboard configuration warning system instead of manually checking the position of the flaps and slats.

The Board's investigation also found that the watch officers failed to use independent alternative means to verify the *Royal Majesty*'s

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[48](a) National Transportation Safety Board. 1986. *China Airlines Boeing 747-SP, N4522V, 300 nautical miles northwest of San Francisco, California, Feb. 19, 1985*. Aviation Accident Report NTSB/AAR-86/03. (b) National Transportation Safety Board. 1984. *Scandinavian Airlines System Flight 901, McDonnell Douglas DC-10-30, John F. Kennedy Airport, Jamaica, New York, February 28, 1984*. Aviation Accident Report NTSB/AAR-84/15. (c) National Transportation Safety Board. 1973. *Eastern Air Lines, Inc., L-1011, N310EA, Miami, Florida, December 29, 1972*. Aviation Accident Report NTSB/AAR-73/14.

[49](a) Parasuraman, R.; Molloy, R.; Singh, I. 1993. "The performance consequences of automation-induced complacency." *The International Journal of Aviation Psychology*, 3(1): 1-23. (b) Kessel, C. J.; Wickens, C. D. 1982. "The transfer of failure-detection skills between monitoring and controlling dynamic systems." *Human Factors*, 24(1), 49-60.

[50]Wiener, E. L.; Curry, R. E. 1980 "Flight deck automation: problems and promises." *Ergonomics*, 23 995-1011.

[51]National Transportation Safety Board. 1988. Northwest Airlines, Inc., *McDonnell Douglas DC-9-382, N312RC, Detroit Metropolitan Wayne County Airport, Romulus, Michigan, August 16, 1987*. Aviation Accident Report NTSB/AAR-88/05.

position. Research on operator monitoring performance suggests that the reliability or trustworthiness of an automated system[52] could have affected the officers' verification of the GPS position data. The complete automated navigation system, including the GPS, on the *Royal Majesty* had proven to be a highly reliable and accurate system, and the watch officers' testimony suggested that they believed the GPS was superior to other onboard position instrumentation. Also, the watchkeeping procedures of the master and the watch officers did not include an effective mechanism for comparing the GPS with other position instrumentation. Although the master required the watch officers to plot fixes manually as an apparent check on the system, this procedure did not provide an independent verification of the GPS information. The Safety Board concludes that the watch officers on the *Royal Majesty* may have believed that because the GPS had demonstrated sufficient reliability over 3 ½ years, the traditional practice of using at least two independent sources of position information was not necessary.

After failing to recognize the mode change on the GPS system, the watch officers had numerous opportunities to detect that the vessel had drifted away from its intended track. The failure of the chief officer and the second officer to recognize that the *Royal Majesty* was off course may be explained by how convincing the display of position information was. The NACOS 25 presented the watch officers with a detailed map view (on the ARPA display) that indicated the position of the ship. The map display provided a very salient and seemingly accurate picture of the *Royal Majesty*'s course. Research on decisionmaking indicates that cues that are most salient, such as the map display, tend to bias operators when they make diagnostic decisions.[53] Further, research on decisionmaking in the presence of automation has indicated that automation can bias an operator's decisions.[54]

Both the chief officer and the second officer exhibited decisionmaking bias toward the automated map display. Based on information from the map display, the chief officer felt no need to visually verify his identification of the BA buoy. The second officer was overly reliant on the map display when he failed to cross check the vessel's position despite repeated indications of the *Royal Majesty's* deviation from its intended track. The Safety Board concludes that all the watchstanding officers were overly reliant on the automated position display of the NACOS 25 and were, for all intents and purposes, sailing the map display instead of using navigation aids or lookout information.

Notwithstanding the merits of advanced systems for high-technology navigation, the Safety Board does not consider the automation of a bridge navigation system as the exclusive means of navigating a ship, nor does the Board believe that electronic displays should replace visually verifiable navigation aids and landmarks. The human operator must have the primary responsibility for the navigation; he must oversee the automation and exercise his informed judgment about when to intervene manually.

As the grounding of the *Royal Majesty* shows, shipboard automated systems, such as the integrated bridge system and the GPS, can have a profound influence on a watchstander's performance. However, the full impact of automated systems on watchstanding performance has yet to be examined in detail. The Coast Guard has begun this effort by examining how automation affects watch officers' tasks and workload. The Safety Board believes further research is necessary. Therefore, the Safety Board recommends that the Coast Guard continue its research on shipboard automation, focusing on watch officers' monitoring and deci-

[52] Mosier, K. L., Skitka, L. J., and Heers, S. T. Automation and Accountability for Performance. In: Proceedings of the 8th International Symposium on Aviation Psychology. Columbus, OG: The Ohio State University, 1995.

[53] Wickens, C. D. 1984. *Engineering Psychology and Human Performance*. Columbus, Ohio: Merrill.

[54] Mosier, K. L.; Skitka, L. J. 1966. "Humans & automation, Made for each other?" In Raja Parasuraman and Mustapha Mouloua. Eds. *Automation and Human Performance: Theory and Applications.* Mahwah, NJ: Lawrence Erlbaum Associates.

sionmaking aboard ships with automated integrated bridge systems.

Integrated Bridge System Design and Location

The performance of the watch officers during the voyage and the circumstances leading to the grounding were linked to several error-inducing deficiencies in the design of the equipment and to an inefficient layout of system displays on the bridge.

Although the Raytheon 920 GPS receiver's NMEA 0183 output data should have been programmed to identify the receiver as an integrated instrument (II) talker with a system mode (*SYS*) sentence to indicate GPS or DR mode, the industry standard NMEA 0183 data protocol did not provide a *SYS* identifier for DR mode. In short, the NMEA did not consider that hybrid mode receivers could use DR as one of their modes of determining position. Consequently, the Raytheon designers chose to use the GPS *GP* identifier in the NMEA 0183 output, regardless of whether the Raytheon 920 GPS device was transmitting valid GPS data or DR-derived position data.

To account for this, however, Raytheon also programmed the Raytheon 920 GPS to automatically set the NMEA 0183 *valid*/*invalid* position data bits to the *invalid* state when the GPS was operating in the SOL and/or DR mode. In doing so, Raytheon assumed that a listener device, such as the NACOS 25, using position data from a GP talker would recognize when the data were flagged *invalid*.

Once the desired position receiver is selected by the crew, the NACOS 25 takes position data from the chosen position receiver based on the "talker" identifier code in the NMEA 0183 data stream; in this case, *GP* in the data stream from the *Royal Majesty*'s Raytheon 920 GPS. STN Atlas designers did not expect a device identifying itself as *GP* to send position data based on anything other than GPS data, particularly not on DR-derived position data. Further, STN Atlas expected inaccurate or failed GPS position data to be recognizable by nulled position data fields or by no change in the position latitude/longitude, the latter of which would trigger the NACOS 25 position-fix alarm. STN Atlas therefore chose not to program the NACOS 25 to check the *valid*/*invalid* bits in the NMEA 0183 data stream as a means of detecting invalid GPS data. Consequently, when the GPS defaulted to the DR mode, the NACOS 25 autopilot was unable to recognize the status change; and thus its subsequent navigation did not correct for the effect of wind, current, or sea. The Safety Board concludes that because the industry standard NMEA 0183 data protocol did not provide a documented or standardized means of communicating or recognizing that a DR positioning mode was in use by a hybrid, DR-capable position receiver, Raytheon and STN Atlas adopted different design philosophies about the communication of position-receiver mode changes for the Raytheon 920 GPS and the NACOS 25.

Nevertheless, STN Atlas was aware of and claimed compatibility with the NMEA 0183 protocol containing the *valid*/*invalid* status bits used by Raytheon and was capable of making the NACOS 25 NMEA 0183 interface fully compatible with those specifications if it wanted to do so (including the recommended minimum GPS data sentence *RMC*). Therefore, the Safety Board further concludes that STN Atlas should have, in order to help ensure safety and compatibility with different NMEA 0183 position receivers, programmed the *Royal Majesty*'s NACOS 25 to recognize the *valid*/*invalid* status bits in the NMEA 0183 data, including those specified in the NMEA 0183 v1.5 *RMC* recommended minimum GPS data sentence. The Safety Board is aware that since the accident, STN Atlas has taken steps to program its integrated navigation system NMEA 0183 interfaces to meet a newer, more comprehensive NMEA 0183 version and to ensure that no DR-capable position receivers are used with its NACOS-integrated navigation system. The Safety Board believes that Raytheon should design its hybrid positioning systems to identify themselves as integrated instruments (II) with an appropriate system mode identifier (*SYS*) in coordination with the NMEA. Further, the Board believes that the NMEA and the IEC should revise their electronic interface standards to provide an explicit means of indicating when hybrid position receivers are transmitting DR-derived position data. Finally, the Board believes that the NMEA and the IEC should advise their members to (1) immediately inform the NMEA and the IEC of perceived inadequacies in electronic interface standards and (2), if applicable, design their hybrid positioning systems to identify themselves ("talk") as integrated instruments (II) with an appropriate system mode identifier (*SYS*).

Although the *Royal Majesty* was equipped with multiple position receivers, the NACOS 25 autopilot was not configured to compare position data from multiple independent position receivers, such as the Raytheon 920 GPS and the 780 Loran-C receivers. Given the *Royal Majesty*'s frequent proximity to land and the expected reasonable accuracy of the Loran-C in that area, the NACOS 25 could have recognized the large discrepancy between the GPS and the Loran-C positions as the vessel approached Nantucket Shoals had it been able to compare them. The Safety Board concludes that had the autopilot been configured to compare position data from multiple independent position receivers and had a corresponding alarm been installed that activated when discrepancies were detected, the accident may have been avoided. The safety benefits associated with the redundancy of such critical systems as position receivers would help prevent such single-point catastrophic failures as occurred on the *Royal Majesty*. The Safety Board believes, therefore, that STN Atlas should design its integrated bridge systems to incorporate multiple independent position receivers, comparison of position data from those receivers, and related crew alerts regarding changes in position-receiver accuracy, selection, and mode.

The NACOS 25 central console provided efficient access to and display of most information needed to conduct a passage when the GPS was fully operational. However, where various sources of position information were possible (i.e., GPS, Loran-C, or DR), as with the NACOS 25 autopilot, it was important to delineate clearly which mode was in use. On the *Royal Majesty*, because the NACOS 25 could not detect the GPS's change to DR mode, the central console display switched from GPS to DR-derived positions without changing its display in any perceivable way or notifying the crew. The integrated bridge system, as configured, did not indicate to the officers at the central console that the navigation system had defaulted to the DR mode.

The design of the integrated bridge system consolidated most of the officers' watchstanding navigation activities at the central console when the *Royal Majesty* was underway. The officer on watch could remain in the console seat for most of his watch and execute maneuvers along with most of the essential navigation tasks. However, key components of the system were installed elsewhere so that the officers needed to leave the console area to do monitoring tasks. In order to cross check the position instrumentation and to verify that the navigation system was not in the DR mode, officers needed to see equipment displays in the chart room behind the console area on the bridge. The GPS and the Loran-C receivers were convenient only when manual chart work was being performed. The Safety Board concludes that because watch officers must verify proper equipment operation frequently, alternative sources of critical equipment status should have been displayed directly on the console or on repeaters located where they could be seen from the central console.

Of particular concern was the alarm system for the GPS. The internal aural alarm for the GPS lasted 1 second, despite its critical function. Neither the brief aural alarm nor the visual alarm, in the form of very small *DR* and *SOL* characters on the GPS receiver's screen, could be easily seen or heard at the command console. Rather, the GPS receiver was in the chart room. The remoteness of the location probably precluded the watch officers' hearing the alarm or initially noticing the *DR* and *SOL* indications when the GPS defaulted to the DR mode. Further, the installer of the integrated bridge system did not connect the GPS receiver's external alarm switch to a loud and continuous external alarm, even though one was available. Had the GPS external alarm been installed or had its internal aural alarm required the user to take action to silence it, the officers would have been alerted to the GPS antenna problem shortly after leaving St. George's. Consequently, the Safety Board concludes that the Raytheon 920 GPS receiver's brief aural alarm, the remoteness of the receiver's location, and the failure of the installer to connect the GPS external alarm resulted in the inadequacy of the aural warning sent to the crew when the GPS defaulted to the DR mode. In view of the foregoing, the Safety Board believes that Raytheon should design its position receivers to provide continuous aural alarms that require the user to take action to silence them. The Board further believes that the NMEA should recommend that its members design and install critical aural alarms that are continuous and require the user to take action to silence them. Finally, the Safety Board believes that the ICCL, the International Chamber of Shipping, and INTERTANKO should recommend to their members that they ensure that integrated bridge systems installed on their vessels provide critical aural alarms that are continuous and require the user to take action to silence them.

The failure of the GPS antenna connection and the subsequent failure of the NACOS 25 autopilot to recognize the GPS data as invalid and to sound an alarm resulted in a single-point, "silent" failure mode on the *Royal Majesty*. Aeronautical and aerospace design safety practices typically require the analysis of potential failure modes via failure modes and effects analyses (FMEAs). FMEAs of the *Royal Majesty*'s integrated bridge system could have highlighted the need for multiple independent comparisons of positioning systems to detect discrepancies between systems, the need for removal of the DR input to the Raytheon 920 GPS receiver, and the need for the NACOS 25 to interrogate the NMEA 0183 *valid/invalid* position data bits. The Safety Board concludes that FMEAs of the *Royal Majesty*'s integrated bridge system would probably have disclosed the shortcomings of the system's components. Therefore, the Safety Board believes that the Coast Guard should propose to the IMO that it develop standards for integrated bridge system design that will require:

- multiple independent position-receiver inputs;
- monitoring position-receiver data for failures/invalid data and subsequent positive annunciation to the crew;
- comparing position-receiver data for significant discrepancies between position receivers, and subsequent positive annunciation to the crew; and
- FMEAs during the design process and once again when all peripheral devices and equip-ment details have been "frozen" if the FMEA during the design process does not account for all peripheral device/equipment variations.

The Safety Board also believes that STN Atlas should recommend that all of its customers have final FMEAs for their installations, because overall integrated bridge system and peripheral device installation details frequently vary from installation to installation.

Further, the Safety Board believes that, in the interim, the ICCL, the International Chamber of Shipping, and INTERTANKO should recommend that each of their members ensure that their existing and new integrated bridge systems incorporate the following:

- multiple independent position-receiver inputs;
- monitoring position-receiver data for failures/invalid data and subsequent positive annunciation to the crew;
- comparing position-receiver data for significant discrepancies between position receivers, and subsequent positive annunciation to the crew; and
- FMEAs on existing systems, during the design process for new systems,

and whenever peripheral devices or equipment details change.

Human Systems Integration

It is apparent that the marine industry is undergoing the same evolution in automation that the aviation and other transportation industries are. Accidents involving automated systems, like the grounding of the *Royal Majesty*, highlight the importance of considering the abilities of the human operator in automated systems. Rothblum et al. concluded:

> Automation is becoming more prevalent on commercial ships, affecting such areas as engineering, bridge, and cargo operations. When designed properly and used by trained personnel, such automation can be helpful in improving operational efficiency and safety. However, when designed poorly or misused by undertrained or untrained personnel, automated equipment can be a contributing cause to accidents. In one study of 100 marine casualties, inadequate knowledge about equipment was found to be a contributing cause in 35 percent of the casualties. The most frequently cited problem was the misuse or nonuse of radar. Lack of training is not the only problem. Poor equipment design can induce the mariner to make mistakes. In the same study, one-third of the accidents were found to be caused partly by poor human-factors design of the equipment.[55]

Inadequate training and poor human-factors design are often the result of applying a technology-centered philosophy to automated systems.[56] This approach seeks to replace mariner functions with machine functions without considering the mariners' capabilities and limitations. As a result, the approach has the effect of leaving the mariner out of meaningful control or active participation in the operation of the ship. A human-centered philosophy towards automation recognizes that the mariner is the central element in the operation of the ship. Consequently, the philosophy emphasizes designs that fully utilize human capabilities and protect against human limitations, such as unreliable monitoring and bias in decisionmaking.

Human systems integration (HSI), part of the systems engineering[57] process addressing the psycho-social aspects of system design, represents a method by which automation can be designed with a human-centered philosophy. HSI addresses such areas as human-factors engineering,[58] training, manpower, and personnel. The types of human engineering analyses associated with HSI (i.e., task analysis, and error analysis) help us to understand the impact of automation on human tasks and on the entire system's performance.

Several standards and guidelines have been produced to ensure that human factors are addressed in system designs, thus reducing the potential for human error. These standards address behaviors related to automation and specify design parameters that keep the systems' operating characteristics within the physical and cognitive capabilities of humans. The U.S. Department of Defense and the National Aeronautics and Space Administration have long recognized the importance of addressing human factors early in the system design, development, and overall acquisition processes and have published relevant human engineering standards and guidelines.[59]

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[55] Rothblum, Sanquist, Lee, and McCallum. "Identifying the Effects of Shipboard Automation on Mariner Qualifications and Training and Equipment Design." Paper prepared for ISHFOB '95: Informational Symposium—Human Factors on Board. Bremen, Germany. November 15-17, 1995.

[56] Norman, S; Billings, C.E.; and others. 1988. Aircraft automation philosophy: A source document. Moffett Field, CA: NASA Ames Research Center.

[57] Systems engineering is the management function that controls the total system development effort for the purpose of achieving an optimum balance of all system elements. Generally, those elements are equipment, software, personnel, facilities, and data. HSI specifically addresses the personnel, or human interactive, aspects of the system.

[58] Human-factors engineering is the application of the principles of human behavior to the design of equipment and systems to enhance performance, safety, and quality.

[59] Department of Defense: DOD 5000.2 "Defense Acquisition Management Policies and Procedures;" MIL-H-46855, "Human Engineering Requirements for Military Systems,

Other sectors of the maritime industry have incorporated human-factors engineering routinely. For example, the American Society of Testing and Materials has adopted much of the Department of Defense human engineering standards in designing off-shore oil platforms.[60] Thus, while human engineering is a known concept in the marine industry, there have not been any unifying efforts to integrate this concept into the marine engineering and manufacturing sector. Additionally, human engineering in the broader context of HSI has been given little or no consideration. Consequently, the potential for error causing behavior related to these systems has not been adequately addressed by the marine industry.

To assess the HSI involved in the automated systems on the *Royal Majesty*, the Safety Board examined the training the officers received and the design of the automated systems in the context of human-factors engineering.

Watch Officers' Training in Using the Integrated Bridge System.—The investigation determined that although the manufacturer of the NACOS autopilot, STN Atlas, had classroom and simulator training available to purchasers of the system, the owner of the *Royal Majesty* had not purchased any training. When the vessel was placed in service, the manufacturer provided an orientation during sea trials to the first complement of officers assigned to the ship; however, of the officers on the *Royal Majesty* at the time of the grounding, only the chief officer had been a part of that complement.

The investigation determined that the watch officers on the *Royal Majesty* during the grounding were familiar with the basic operation of the automated navigation equipment, but that no one, with the possible exception of the navigator, appeared to be fully proficient with the system, as evidenced by the lack of knowledge about the GPS receiver's DR mode capability. The crew's automated navigation equipment training consisted primarily of on-the-job training, the type of training on which the marine industry has historically relied. For example, the second officer's preparation to operate the automated navigation system was described as him reading the equipment manuals acquired with the system installation, observing bridge operations by the other officers, and using the equipment under their supervision. Because the second officer's introduction to the system consisted of watching others or operating the system himself during routine conditions, he probably had very little experience in recognizing and coping with system malfunctions.

The Safety Board has long supported on-the-job training as an important aspect of an operator's training. However, with the implementation of sophisticated, automated navigational equipment, the Safety Board believes that on-the-job training alone may not be sufficient. The Safety Board is particularly concerned that there were no procedures to determine the proficiency of the officers in operating the automated navigation system, including the navigator who, according to his testimony, was responsible for all instruments on the bridge and the orientation and training of new officers. The Safety Board concludes that the on-the-job training program employed by Majesty Cruise Line to train the *Royal Majesty*'s watch officers in the operation of the integrated bridge system did not adequately prepare the officers to identify and respond to system malfunctions. Therefore, the Safety Board believes that Majesty Cruise Line should provide initial and recurrent formal training on essential technical information, equipment functions, and system operating procedures to all bridge watchstanding personnel on all of its ships that are equipped with integrated bridge systems. The Safety Board also believes that the ICCL should encourage its members to take the same steps.

As discussed earlier, the watch officers, in particular the second officer and the chief officer, abandoned the good watchstanding practices of properly monitoring and cross checking the progress of their vessel and instead relied

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Equipment, and Facilities;" MIL-STD-1472, "Human Engineering Design Criteria for Military Systems, Equipment, and Facilities;" MIL-STD 1800, "Human Factors Engineering;" MIL-STD 1801, "User-System Interface."

[60] ASTM Standard F1166-88, Standard practice for human engineering design for marine systems, equipment and facilities. ASTM Philadelphia, Pennsylvania.

almost solely on the GPS and the ARPA display to provide them with information about the vessel's movements. The circumstances of the grounding of the *Royal Majesty* and the discussions at the Safety Board's public forum suggest that there is a need for the international maritime community to address the issue of improving training for deck officers assigned to vessels equipped with electronic navigation equipment and integrated bridge systems. The Safety Board is concerned that the inadequacy of training given to the crew of the *Royal Majesty* in the use of sophisticated electronic navigation equipment and integrated bridge systems may be typical of the industry. Therefore, the Safety Board believes that the Coast Guard should propose to the IMO that it develop appropriate performance standards for the training of watch officers assigned to vessels equipped with sophisticated electronic navigation equipment and integrated bridge systems and then require this training.

The deficient monitoring of the integrated navigation system by the deck officers and the second officer's failure to recognize the danger to the *Royal Majesty* before the grounding point to the usefulness of training in bridge resource management. As shown by its issuance of Safety Recommendations M-93-18, and -19, the Safety Board has advocated such training for deck officers who operate conventional navigation bridges. The grounding of the *Royal Majesty*, however, shows the need to address procedures for and training in effective monitoring of automated navigation equipment.

Bridge resource management training adapted for watch officers working with fully automated navigation systems or integrated bridge systems could improve the officers' performance. The training would help them make decisions that are not biased by their use of automated equipment. It would improve their situational awareness,[61] which, research shows,[62] declines when operations are automated.

On June 25, 1993, as a result of its investigation of the grounding of the United Kingdom passenger vessel RMS *Queen Elizabeth 2* (near Cuttyhunk Island, Vineyard Sound, Massachusetts, on August 7, 1992, the Safety Board issued Safety Recommendations M-93-18 and -19 to the Coast Guard. The Safety Board requested that the Coast Guard:

> Propose to the IMO that standards and curricula be developed for bridge resource management training for the masters, deck officers, and pilots of ocean-going ships. (M-93-18)
>
> Propose to the IMO that the masters, deck officers, and pilots of ocean-going ships be required to successfully complete initial and recurrent training in bridge resource management. (M-93-19)

On September 27, 1993, responding to Safety Recommendation M-93-18, the Coast Guard Commandant wrote:

> I partially concur with this recommendation. The U.S. will propose at the 25th Session of the IMO Subcommittee on STW that standards and curricula be developed for bridge resource management training for masters and deck officers of seagoing ships. However, the Coast Guard views pilot qualifications as a matter for port State regulation. I will keep the Board informed of our progress regarding this recommendation.

On January 7, 1994, the Safety Board responded:

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[61] *Situational awareness* is a concept referring to perception of an operating environment, comprehension of events and circumstances pertaining to that environment, and a projection of their status. Endsley, M., *Situational Awareness*. Presentation to National Transportation Safety Board, June 6, 1996.

[62] Pew, R.W. Situational *Awareness and its Analysis in Accident Situations.* Presentation by Bold, Beranek and Newman, Inc., to the National Transportation Safety Board, June 7, 1995. Also, Endsley, M.L. and Kiris, E.O., *The Out-of-the-Loop Performance Problem: Impact of Level of Automation and Situational Awareness., ref.* In Mouloua, M. and Parasuraman, R., Eds., *Human Performance in Automated Systems: Current Research and Trends*, Hillsdale, New Jersey, Lawrence Erlbaum Associates, 1994. Pp. 51,55.

> The Safety Board agrees that, in the end, pilot qualifications are a matter for the port State to enforce. The intent of the recommendation is for the IMO to develop a specified standard that would serve as a model that the port States could adopt. The United States has recently been more receptive to the idea of developing a unilateral standard if it is included in the Standards of Training and Watchkeeping. Consequently, the Board encourages the Coast Guard to pursue this issue at the IMO. Because the Coast Guard states it will propose the recommendation to the IMO, Safety Recommendation M-93-18 has been classified "Open--Acceptable Response," pending implementation by the IMO.

On September 27, 1993, responding to Safety Recommendation M-93-19, the Coast Guard Commandant wrote:

> I partially concur with this recommendation. The United States will propose that IMO agree in principle to requiring masters and deck officers on seagoing ships to complete initial and recurrent training in bridge resource management. However, the Coast Guard views pilot qualifications as a matter for port State regulation. I will keep the Board informed of our progress regarding this recommendation.

On January 7, 1994, the Safety Board responded that for the reasons stated in the discussion of Safety Recommendation M-93-18, the Safety Board encouraged the Coast Guard to actively promote the IMO's acceptance of Safety Recommendation M-93-19. Because the Coast Guard had agreed to "proposing in principle" the recommendation, the Board classified Safety Recommendation M-93-19 "Open--Acceptable Alternate Response," pending the outcome of the Coast Guard's efforts.

Therefore, the Safety Board reiterates Safety Recommendations M-93-18 and -19 and urges the Coast Guard to work closely with the IMO in order to expedite the intended outcome of these recommendations.

The Safety Board also believes that the Coast Guard, as part of the foreign flag passenger ship control verification examination program, should assess the adequacy of installed integrated bridge systems and verify that the ships' officers are properly trained in their operation and possible failure modes. Furthermore, as part of the same program, the Coast Guard should verify that the watchstanding procedures of ships' officers include the use of multiple independent means of position verification.

Human-factors Engineering.—Where multiple modes of operation are possible on a system, an important human-factors engineering principle is the clear delineation to the operator of what mode is in use and of when a change in mode occurs. Because different operating procedures may be required for the different modes in use, the operator must be aware of the mode to remain in the decisionmaking process. Thus, the display of which modes and functions are in use should be clearly evident to the operator.

A good example of automation mode confusion occurred on January 20, 1992, when an Air Inter Airbus A320 crashed on a mountainside while on approach to the Strasbourg-Entzheim Airport. The French Transport Ministry's investigation determined that the pilots had become confused with the vertical speed/flight path angle display mode on the A320's flight control unit and had entered a 3,300 foot/minute automatic rate of descent instead of an intended 3.3 angle of descent to the airport. The displays of the vertical speed and the flight path angle were almost identical and thus easily confused.

Not only did the GPS receiver on the *Royal Majesty* display the DR coordinates in the same character size and format as the coordinates derived from satellite data, it switched to the DR mode automatically, without requiring a human to acknowledge that the mode was acceptable. However, as previously discussed, deficiencies in the alarm, the distance of the receiver from the operator, and the inadequacy of the crew's procedures also contributed to the crew's failure to recognize the change to DR mode.

The size of characters, the viewing distance, and the use of contrasting colors are a few of the factors that should be considered in designing character displays for alerts and warnings. Alert messages and status indicators about critical information, such as the GPS defaulting to the DR mode, should be distinctively displayed. In this case, the *SOL* and *DR* alert messages were much smaller than the normal status information.

An operator may also become desensitized when an alert appears frequently with normal status information. In this case, whenever chopping occurred, *SOL* and *DR* were displayed. The watch officers had noticed these messages many times before and perhaps had learned to pay little attention to them.

The Safety Board concludes that the *Royal Majesty*'s integrated bridge system had several shortcomings with respect to human-factors engineering. First, mode information was not available to the crew at the central console (the normal position). Second, the GPS/DR alarm and status indicators, which could have alerted the crew to the mode change, were either not installed (external alarm) or not salient enough (internal alarm) to attract the watchstanders' attention. Finally, the integrated bridge system as implemented on the *Royal Majesty* failed to adequately define the watch officers' tasks and procedures. If the automation on board the *Royal Majesty* had been appropriately implemented and integrated with the human operator, the vessel probably would not have grounded. Because of the Safety Board's concern that automation on other vessels has not been appropriately implemented and integrated with the human operator, the Board believes that the Coast Guard should propose to the IMO that it apply existing human-factors engineering standards in the design of integrated bridge systems on vessels.

Certification of Integrated Bridge Systems

A draft IMO performance standard for integrated bridge systems is currently under review and is expected to be adopted and implemented by 1999. At the Safety Board's public forum on integrated bridge systems, manufacturers of integrated bridge systems pointed out that integrating the various components like ARPA, autopilot, electronic chart system (or radar map), and monitoring systems involves careful matching and FMEAs to eliminate any potential interface problems. The recently developed interface standards from the IEC and the NMEA (IEC 1162-2 and NMEA 0183) should facilitate the matching of subsystems manufactured by one manufacturer to an integrated bridge system manufactured by another. These standards and an IMO performance standard should eliminate many of the potential interface problems. The Safety Board concludes that there is a need to have performance standards for integrated bridge systems, and to require that the systems be inspected and certified.

The proposed IMO performance standard for integrated bridge systems includes a requirement that the manufacturers of integrated bridge systems be certified by the ISO. Thus, it would appear that the safeguards for guaranteeing the quality of software during manufacturing likely will become an IMO requirement. Such a requirement could ensure that the people responsible for developing the software are well qualified and that the manufacturer has procedures for verifying the quality of the software.

Developments in electronic equipment, however, are very rapid, and it is sometimes possible for developments to occur more quickly than standards can be produced. Further, the possibility exists that software may be changed, possibly inappropriately, during the life of an integrated bridge system. Therefore, the selection and matching of electronic equipment will still require highly qualified personnel who are familiar with the equipment, the data to be transmitted, the format of the data, and the applicable standards. The Safety Board believes that there is a need for some competent authority to conduct continuing oversight to ensure that future changes in subsystems or software on integrated bridge systems are compatible and that system integrity is maintained. Also, the Safety Board believes that certifying navigation bridges equipped with integrated bridge systems should be done by a qualified, independent authority. In summary, the Safety Board believes that the Coast Guard should propose to the IMO that a provision be included in the performance standard for integrated bridge systems that would require that a competent independent authority inspect and certify the navigation bridge of each commercial vessel equipped with an integrated bridge system when the system is installed and periodically throughout its life.

CONCLUSIONS

1. The weather, the mechanical condition of the *Royal Majesty*, except for the global positioning system receiver, the officers' certifications, drugs, and fatigue were not factors in the accident.

2. Although Coast Guard personnel observed no indications that the officers had been under the influence of alcohol, alcohol could not be conclusively ruled out as a factor in the accident because of the delay in collecting the blood and urine specimens.

3. About 52 minutes after the *Royal Majesty* left St. George's, Bermuda, the global positioning system receiver antenna cable connection had separated enough that the global positioning system switched to dead-reckoning mode, and the autopilot, not programmed to detect the mode change and invalid status bits, no longer corrected for the effects of wind, current, or sea.

4. Openly routing the global positioning system antenna cable in an area where someone occasionally walked increased the risk of damage to the cable and related connectors.

5. Had the fathometer alarm been set to 3 meters, as was the stated practice, or had the second officer chosen to display the fathometer data on the control console, he would have been alerted that the *Royal Majesty* was in far shallower water than expected and, thus, was off course. He would have been alerted perhaps as long as 40 minutes before the grounding, and the situation could have been corrected.

6. The watch officers' monitoring of the status of the vessel's global positioning system was deficient throughout the voyage from St. George's.

7. Deliberate cross checking between the global positioning system and the Loran-C to verify the *Royal Majesty*'s position was not being performed and should have been on the voyage from St. George's.

8. Even though it is likely that the watch officers were not aware of the limitation inherent in using the position-fix alarm to monitor the accuracy of GPS position data, it was inappropriate for them to rely solely on the alarm to warn them of any problems with the GPS data.

9. The sighting of lights not normally observed in the traffic lanes, the second officer's inability to confirm the presence of the BB buoy, and the sighting of blue and white water should have taken precedence over the automation display on the central console and compelled the second officer to promptly use all available means to verify his position.

10. The chief officer and the second officer did not observe good watchkeeping practices or act with heightened awareness of the precautions that are needed when a vessel approaches the Boston traffic lanes and landfall.

11. The master's methods for monitoring the progress of the voyage did not account for the technical capabilities and limitations of the automated equipment.

12. The watch officers on the *Royal Majesty* may have believed that because the global positioning system had demonstrated sufficient reliability over 3 1/2 years, the traditional practice of using at least two independent sources of position information was not necessary.

13. All the watchstanding officers were overly reliant on the automated position display of the navigation and command system 25 and were, for all intents and purposes, sailing the map display instead of using navigation aids or lookout information.

14. Because the industry standard 0183 data protocol did not provide a documented or standardized means of communicating or recognizing that a dead-reckoning positioning mode was in use by a hybrid, dead reckoning capable position receiver, Raytheon and STN Atlas adopted different design philosophies about the communication of position-receiver mode changes for the Raytheon 920 global positioning system and the navigation and command system 25.

15. STN Atlas should have, in order to help ensure safety and compatibility with different National Marine Electronics Association (NMEA) 0183 position receivers, programmed the *Royal Majesty*'s navigation and command system 25 to recognize the *valid*/*invalid* status bits in the NMEA 0183 data, including those specified in the NMEA 0183 v1.5 *RMC* recommended minimum global positioning system data sentence.

16. Had the navigation and command system 25 autopilot been configured to compare position data from multiple independent position receivers and had a corresponding alarm been installed that activated when discrepancies were detected, the grounding of the *Royal Majesty* may have been avoided.

17. Because watch officers must verify proper equipment operation frequently, alternative sources of critical equipment status should have been displayed directly on the console or on repeaters located where they could be seen from the central console.

18. The brief aural alarm of the Raytheon 920 global positioning system receiver, the remoteness of the receiver's location, and the failure of the installer to connect the global positioning system external alarm resulted in the inadequacy of the aural warning sent to the crew when the global positioning system defaulted to the dead-reckoning mode.

19. Failure modes and effects analyses of the *Royal Majesty*'s integrated bridge system would probably have disclosed the shortcomings of the system's components.

20. The on-the-job training program employed by Majesty Cruise Line to train the *Royal Majesty*'s watch officers in the operation of the integrated bridge system did not adequately prepare these officers to identify and respond to system malfunctions.

21. The *Royal Majesty's* integrated bridge system did not adequately incorporate human-factors engineering.

22. There is a need to have performance standards for integrated bridge systems, and to require that the systems be inspected and certified.

PROBABLE CAUSE

The National Transportation Safety Board determines that the probable cause of the grounding of the *Royal Majesty* was the watch officers' overreliance on the automated features of the integrated bridge system, Majesty Cruise Line's failure to ensure that its officers were adequately trained in the automated features of the integrated bridge system and in the implications of this automation for bridge resource management, the deficiencies in the design and implementation of the integrated bridge system and in the procedures for its operation, and the second officer's failure to take corrective action after several cues indicated the vessel was off course.

Contributing factors were the inadequacy of international training standards for watchstanders aboard vessels equipped with electronic navigation systems and integrated bridge systems and the inadequacy of international standards for the design, installation, and testing of integrated bridge systems aboard vessels.

RECOMMENDATIONS

As a result of its investigation of this accident, the National Transportation Safety Board reiterates the following recommendations:

To the U.S. Coast Guard:

> Propose to the International Maritime Organization that standards and curricula be developed for bridge resource management training for the masters, deck officers, and pilots of ocean-going ships. (M-93-18)
>
> Propose to the International Maritime Organization that the masters, deck officers, and pilots of ocean-going ships be required to successfully complete initial and recurrent training in bridge resource management. (M-93-19)

Also as a result of the investigation, the National Transportation Safety Board makes the following recommendations:

To Majesty Cruise Line:

> Provide initial and recurrent formal training on essential technical information, equipment functions, and system operating procedures to all bridge watchstanding personnel on all its ships that are equipped with integrated bridge systems. (M-97-1)
>
> Review the bridge watchstanding practices on all its vessels, and revise, as necessary, to ensure that all watch officers adhere to sound watchstanding practices and procedures, including using landmarks, soundings, and navigational aids to verify a vessel's position, relying on more than one source for position information, and reporting to the master any failure to detect important navigational aids. (M-97-2)
>
> Periodically review the performance of all officers on board its vessels. (M-97-3)
>
> Eliminate the practice of openly routing navigation equipment cable to decrease the risk of damage. (M-97-4)

To the U.S. Coast Guard:

> Propose to the International Maritime Organization that it develop appropriate performance standards for the training of watch officers assigned to vessels equipped with sophisticated electronic navigation equipment and integrated bridge systems and then require this training. (M-97-5)
>
> Propose to the International Maritime Organization that it develop standards for integrated bridge system design that will require
>
> - multiple independent position-receiver inputs;
> - monitoring position-receiver data for failures/invalid data and subsequent positive annunciation to the crew;
> - comparing position-receiver data for significant discrepancies between position receivers, and subsequent positive annunciation to the crew; and
> - failure modes and effects analyses (FMEAs) during the design process and once again when all peripheral devices and equipment details have been "frozen" if the FMEA during the design process does not account for all peripheral device/equipment variations. (M-97-6)
>
> Propose to the International Maritime Organization that it apply existing human-factors engineering standards in the design of integrated bridge systems on vessels. (M-97-7)

Propose to the International Maritime Organization that a provision be included in the performance standard for integrated bridge systems that would require that a competent independent authority inspect and certify the navigation bridge of each commercial vessel equipped with an integrated bridge system when the system is installed and throughout its life. (M-97-8)

Continue its research on shipboard automation, focusing on watch officers' monitoring and decisionmaking aboard ships with automated integrated bridge systems. (M-97-9)

As part of the foreign flag passenger ship control verification examination program, assess the adequacy of installed integrated bridge systems and verify that the ships' officers are properly trained in their operation and possible failure modes. (M-97-10)

As part of the foreign flag passenger ship control verification examination program, verify that the watchstanding procedures of ships' officers include the use of multiple independent means of position verification. (M-97-11)

To STN Atlas Elektronik GmbH:

Design its integrated bridge systems to incorporate multiple independent position receivers, comparison of position data from those receivers, and related crew alerts regarding changes in position-receiver accuracy, selection, and mode. (M-97-12)

Recommend that all its customers have final failure modes and effects analyses for their integrated bridge system installations. (M-97-13)

To Raytheon Marine:

Design its hybrid positioning systems to identify themselves as integrated instruments (II) with an appropriate system mode identifier (*SYS*) in coordination with the National Marine Electronics Association. (M-97-14)

Design its position receivers to provide continuous aural alarms that require the user to take action to silence them. (M-97-15)

To the National Marine Electronics Association:

Revise the 0183 electronic interface standard to provide an explicit means of indicating when hybrid position receivers are transmitting dead reckoning-derived position data. (M-97-16)

Advise its members to (1) immediately inform the National Marine Electronics Association and the International Electrotechnical Commission of perceived inadequacies in electronic interface standards and (2), if applicable, design their hybrid positioning systems to identify themselves ("talk") as integrated instruments (II) with an appropriate system mode identifier (*SYS*). (M-97-17)

Recommend to its members that they design and install critical aural alarms that are continuous and require the user to take action to silence them. (M-97-18)

To the International Electrotechnical Commission:

Advise its members to (1) immediately inform the National Marine Electronics Association and the International Electrotechnical Commission of perceived inadequacies in electronic interface standards and (2) if applicable, design their hybrid positioning systems to identify themselves ("talk") as integrated instruments (II) with an appropriate system mode identifier (*SYS*). (M-97-19)

Revise the 1162 electronic interface standard to provide an explicit means of indicating when hybrid position receivers are transmitting dead reckoning-derived position data. (M-97-20)

To the International Council of Cruise Lines:

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. (M-97-21)

Recommend that its members review the bridge watchstanding practices on all their vessels, and revise as necessary to ensure that all watch officers adhere to sound watchstanding practices and procedures, including using landmarks, soundings, and navigational aids to verify a vessel's position, relying on more than one source for position information, and reporting to the master any failure to detect important navigational aids. (M-97-22)

Recommend that its members periodically review the performance of all officers on board their vessels. (M-97-23)

Recommend that its members eliminate the practice of openly routing navigation equipment cable to decrease the risk of damage. (M-97-24)

Recommend to its members that they ensure that integrated bridge systems installed on their vessels provide critical aural alarms that are continuous and require the user to take action to silence them. (M-97-25)

Recommend that its members ensure that their existing and new integrated bridge systems incorporate the following:

- multiple independent position-receiver inputs;
- monitoring position-receiver data for failures/invalid data and subsequent positive annunciation to the crew;
- comparing position-receiver data for significant discrepancies between position receivers, and subsequent positive annunciation to the crew; and
- failure modes and effects analyses on existing systems, during the design process for new systems and whenever peripheral devices or equipment details change. (M-97-26)

To the International Chamber of Shipping and to the International Association of Independent Tanker Owners:

Recommend to its members that they ensure that integrated bridge systems installed on their vessels provide critical aural alarms that are continuous and require the user to take action to silence them. (M-97-27)

Recommend that its members ensure that their existing and new integrated bridge systems incorporate the following:

- multiple independent position-receiver inputs;
- monitoring position-receiver data for failures/invalid data and subsequent positive annunciation to the crew;
- comparing position-receiver data for significant discrepancies between position receivers, and subsequent positive annunciation to the crew; and

- failure modes and effects analyses on existing systems, during the design process for new systems and whenever peripheral devices or equipment details change. (M-97-28)

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

JAMES E. HALL
Chairman

ROBERT T. FRANCIS II
Vice Chairman

JOHN A. HAMMERSCHMIDT
Member

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Member

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Member

April 2, 1997

APPENDIX A

INVESTIGATION

About 2225 on June 10, 1995, the Panamanian passenger ship *Royal Majest*y, carrying 1,509 passengers and crewmembers, grounded on Rose and Crown Shoal about 10 miles east of Nantucket Island, Massachusetts.

The Safety Board was notified of the grounding early on June 11, 1995. On Monday morning (June 12th), a Go-Team (an investigator-in-charge, an operations specialist, and, later, an aerospace engineer) were dispatched to the scene. When the team arrived on board the vessel, it had already proceeded to Boston. However, because the accident occurred in international waters, beyond the 3-mile limit, the Safety Board lacked jurisdiction to investigate. The Board then requested and was given permission by the Coast Guard to participate as a party in interest at the Coast Guard Marine Board of Inquiry.

Sworn testimony was taken in Boston, Massachusetts, from June 13 through June 16, 1995. Because the Safety Board was participating as a party in interest, the scope of its investigation into the accident was limited to the information obtained from the Coast Guard Marine Board. The Board did not have the authority to depose individuals and subpoena important records.

The Safety Board has considered all facts in the investigative record that are pertinent to the Board’s statutory responsibility to determine the probable cause of this accident and to make recommendations. This report is based on the information collected and the analyses made during the Safety Board’s investigation.

APPENDIX B

MAJESTY CRUISE LINE'S

ROYAL MAJESTY'S "BRIDGE PROCEDURES GUIDE"

The purpose of this guide is to provide you with a description of day-to-day Bridge procedures that are recognized as good practice and to promote through them safety of the *Royal Majesty*, her passengers and crew. This guide is posted on the Bridge so that you may keep yourselves thoroughly familiar with its content which is not written in an arbitrary manner but with sincere wish that you will understand your responsibilities and perform your duties in a professional manner.

The officer on watch is my representative, and your primary responsibility at all times is the safe navigation of the vessel. You must at all times comply with the *1972 International Regulations for Preventing Collisions At Sea.*

You should keep your watch on the Bridge, which you should in no circumstances leave until properly relieved. A prime responsibility of the Officer on Watch is to ensure the effectiveness of the navigating watch. It is of essential importance that all times you ensure that an efficient lookout is maintained. You may visit the chart room, when essential, for short periods for the necessary performance of your navigational duties, but you should previously satisfy yourself that it is safe to do so and ensure that a good lookout is kept.

You continue to be responsible for the safe navigation of the vessel despite my presence on the Bridge until I inform you specifically that I have assumed responsibility.

You should not hesitate to use the sound signaling apparatus at your disposal in accordance with the *1972 International Regulations for Preventing Collisions At Sea.*

You are responsible for the maintenance of a continuous and alert lookout. This is the most important consideration in the avoidance of casualties. The keeping of an efficient lookout requires to be interpreted in its fullest sense which includes the following: A) An alert all round visual and aural lookout to ensure a full grasp of the current situation including the presence of ships and landmarks in the vicinity. B) Close observation of the movements and compass bearing of approaching vessels. C) Identification of ships and shore lights. D) The need to ensure that the course is steered accurately and that wheel orders are correctly executed. E) Observation of the radar and echo sounder displays. F) Observation of changes in the weather, especially the visibility.

You should bear in mind that the engines are at your disposal. You should not hesitate to use them in case of need. However, timely notice of engine movements should be given when possible. You should also keep prominently in mind the maneuvering capabilities of this ship, including its stopping distances.

CONTROL OF MAIN ENGINES: There are two aspects with which you are mainly concerned: (A) Control of revolutions and pitch ahead and astern. You should be familiar with the operation of the engine/propellers control mechanism, bow thrusters, and rudders.

CHANGING OVER THE WATCH: The relieving officer on watch should ensure that members of his watch are fully capable of performing their duties and, in particular, that they are adjusted to night vision. You should not take over the watch until your vision is fully adjusted to the light conditions and you have personally satisfied yourself regarding: A) Standing orders and other special instructions relating to the navigation of the vessel. B) The position, course, speed, and draught of the vessel. C) Prevailing and predicted tides, currents, weather, visibility, and the effect of these factors upon course and speed. D) The navigational situation including: i) The operational condition of all navigation and safety equipment. ii) Errors of gyro and magnetic compasses. iii) The movement of vessels in the vicinity. iv) Conditions and hazards likely to be encountered during the watch. v) The possible effects of heel, trim, water density, and squat on under keel clearances. If at any time you are to be relieved, a maneuver or other action to avoid any hazard is taking place, your relief should be deferred until such action is completed. You should not hand over the watch to the relieving officer if you have any reason to believe that the latter is under any disability which would preclude him from carrying out his duties effectively. If in doubt, you should inform me at once.

You should make regular checks to ensure that: A) The helmsman or the autopilot is steering the correct course. B) The standard compass error is established at least once a watch and, when possible, after any major alteration of course. C) The standard and gyro compasses are compared frequently and repeaters synchronized. D) The automatic pilot is tested in the manual position at least once a watch. E) The navigation and signal lights and other navigation equipment are functioning properly.

HELMSMAN/AUTOMATIC PILOT: You should bear in mind the need to station the helmsman and change over the steering to manual control in good time to allow any potentially hazardous situation to be dealt within a safe manner. With a vessel under automatic steering, it is highly dangerous to allow a situation to develop to the point where you are without assistance and have to break the continuity of the lookout in order to take emergency action. The change-over from automatic to manual steering and visa versa should be made by or under the supervision of a responsible officer.

NAVIGATION IN COASTAL WATERS: The largest scale chart on board, suitable for the area and corrected with the latest information, should be used. You should identify positively all relevant navigation marks. Fixes should be taken at intervals whose frequency must depend upon factors such as distance from nearest hazard, speed of ship, set experienced, etc. In cases such as a planned approach to an anchor berth or harbor entrance, fixing may be virtually continuous.

RESTRICTED VISIBILITY: When restricted visibility is encountered or suspected, your first responsibility is to comply with *1972 International Regulations for Preventing Collisions At Sea* with particular regard to the sounding of fog signals, use of safe speed and availability of engines for immediate maneuver. In addition you should A) Inform me. B) Post lookout(s), helmsman and in congested areas, revert to hand-steering immediately, C) Exhibit navigation lights. D) Operate and use the radar. All of the above actions should, if possible, be taken in good time before visibility deteriorates.

CALLING THE MASTER: You should notify me immediately under the following circumstances: A) If visibility is deteriorating. B) If the movements of other vessels are causing concern. C) If difficulty is experienced in maintaining course. D) On failure to sight land or a navigation mark or to obtain a sounding by the expected time. E) If either land or a navigation mark is sighted or a marked change in the soundings occurs unexpectedly. F) On the breakdown of the engines, steering gear, or any other essential navigational equipment. G) If any doubt about the possibility of weather damage. H) In any other situation in which you are in doubt. Despite the requirement to notify me immediately in the foregone circumstances, you should not hesitate to take immediate action for the safety of the ship, where circumstances so require.

NAVIGATION WITH PILOT EMBARKED: The presence of a pilot does not relieve you from your duties and obligations. You should cooperate closely with the pilot and maintain an accurate check on the vessel’s position and movements. Alterations of course and/or changes in wheel and/or engine orders should be transmitted through you. If you are in any doubt as to the pilot’s actions or intentions, you should seek clarification from the pilot and, if still in doubt, notify me immediately and take whatever action is necessary before I arrive.

<u>THE WATCHKEEPING PERSONNEL</u>: You should give watchkeeping personnel all appropriate instructions and information which will remove the keeping of a safe watch, including a proper lookout.

<u>SHIP AT ANCHOR</u>: If I consider it necessary, a continuous navigational watch should be maintained in such circumstances, you should: A) Determine and plot the vessel's position on the appropriate chart as soon as possible and, at sufficiently frequent intervals, check by taking bearings of fixed navigational marks, or readily identifiable shore objects, whether the anchor is holding. B) Ensure that an effective lookout is maintained. C) Ensure that an inspection of the vessel is made periodically. D) Observe weather, tidal, and sea conditions. E) Notify me and undertake all necessary measures if the vessel drags. F) Ensure that the state of readiness of the main engines and other machinery is in accordance with my instructions. G) Notify me if visibility deteriorates and comply with the *1972 International Regulations for Preventing Collisions at Sea.* H) Ensure that the vessel exhibits the appropriate lights and shapes and that appropriate sound signals are made at all times.

In conclusion, I will always be available to you for advice you may need and I hope that you will at all times endeavor to do your utmost for the benefit of all on board.

STRICT ATTENTION TO DUTY HAS ITS AWARDS.

MASTER
M/V *Royal Majesty*

[This is a retyped copy of the *Royal Majesty*'s "Bridge Procedures Guide," which was presented as an exhibit during sworn testimony taken by the joint Coast Guard/Safety Board investigation board.]

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APPENDIX C

MAJESTY CRUISE LINE'S CIRCULAR NO. 9

DUTIES OF THE OFFICER ON WATCH	OPS	3

CIRCULAR NO. 9 PAGE 3

JULY 1992

1. The paper work required during the watch is to be done on the bridge done in the bridge, never in the chartroom. When you need to go to the chartroom you should be brief.

2. Smoking in the chartroom is not allowed.

3. One quartermaster is to always be on the lookout position.

4. Check the compasses during your watch twice, and enter the readings in the relevant book. Check the course, the position, navigation lights, traffic in the area, course and distance of ships in the vicinity before you take over the watch.

5. Check the compass error at least once during your watch (weather condition permitting) and enter the readings in the relevant book.

6. Check the ship's position as often as conditions and circumstances allow, but never longer than 30 minute intervals.

7. You summon the Master to the bridge when:

   a) The visibility is less than 5 miles.
   b) The wind changed direction, which could cause drifting from course.
   c) Another ship is crossing the bow and the bearings are steady.
   d) You have doubts about the position.
   e) Traffic is congested or ship is about to pass dangerous areas.

8. If the Master is not in his office and cannot be found immediately, use the P.A. system by saying "THIS IS THE BRIDGE" Never say "THE CAPTAIN IS REQUESTED ON THE BRIDGE. "

9. In case of fog, after you have summoned the Master to the bridge, do the following:

   a) Engines on "stand by. "
   b) Radar "on."
   c) Whistle "on."
   d) Switch from auto pilot to hand steering.
   e) Close the watertight doors.
   f) One quartermaster on the "lookout" position on the bridge and one AB at the bow.
   g) Plot the course, position, and speed of all ships in the vicinity.
   h) When the fog has cleared, recall all above actions.

10. Never pass another ship, land, or any other object less than 1.5 miles distance.

11. Start maneuvering the ship to avoid a collision, never less than 3 miles distance.

12. Close all the portholes and headlights during bad weather conditions.

13. One radar is to always be "ON" if the conditions require so. Relevant entry is to be made in the radar book.

14. Never leave your position before you are relieved by the Officer of the next watch.

15. Always be alert during your watch.

APPENDIX D

POSTACCIDENT TESTING OF GPS RECEIVER AND ANTENNA

The Raytheon RAYSTAR 920 Global Positioning System (GPS) receiver and antenna used for navigation during the grounding of the *Royal Majesty* were tested at Raytheon headquarters on July 6, 1995.[1] Present for the tests were representatives from the National Transportation Safety Board, Raytheon Marine, and Majesty Cruise Line. A new Raytheon RAYSTAR 920 GPS receiver and antenna, randomly removed from Raytheon stock, were first tested to establish a baseline for functionality and performance. The Raytheon GPS receiver and antenna from the *Royal Majesty* were then tested for comparison. Speed log and gyro compass inputs from bench test equipment were used to simulate dead reckoning (DR) data inputs when necessary. The test results follow:

- The Raytheon RAYSTAR 920 GPS receiver and antenna from the *Royal Majesty* functioned per design and in a like manner to that of a new Raytheon RAYSTAR 920 GPS receiver and antenna.

- An "open" in the GPS antenna cable shield wire, such as would result if the shield wire pulled out of any connector leading to the antenna, results in the GPS receiver going into the SOL and DR modes within 2 to 3 seconds of the "open" being established, regardless of whether speed/course data are being input to the GPS receiver.

- As few as 1 to 3 strands of GPS antenna cable shield wire permit continued operation of the antenna pre-amp and, therefore, system functionality.

- As long as the Raytheon 920 GPS receiver's internal audio alarm function is active (user selectable; "ON" in the case of the *Royal Majesty*'s unit), going from a satellite fix condition to the SOL and DR modes results in a brief (<1 second) audio alarm chime (similar to a wristwatch alarm in volume and tone).

- As long as the Raytheon 920 GPS receiver's external alarm function is active (user selectable), going from a satellite fix condition to the SOL and DR modes results in a continuous closing of the external alarm contacts (which could be used to wire up external or remote audio alarms of various forms).

- When satellite data input is removed from the operating Raytheon 920 GPS receiver and speed/course data (e.g., DR data) are available, a single audio alarm chime is emitted, and the receiver continues to output NMEA 0183 v1.5 data, with the LAT/LONG portion of the NMEA 0183 v1.5 data continuing to update based on the DR data and the last GPS position.

- When both satellite data and speed/course data (e.g., DR data) inputs are removed from the operating Raytheon GPS receiver, two brief and separate audio alarm chimes are emitted, and the receiver continues to output NMEA 0183 v1.5 data; but the LAT/LONG portion of the NMEA 0183 v1.5 data stay fixed at the last position.

- An "open" in the antenna cable center conductor results in the GPS receiver going into the SOL and DR modes within 2 to 3 seconds of the "open" being established, regardless of whether speed/course data are being input to the GPS receiver.

[1]The Safety Board has maintained possession of the *Royal Majesty*'s GPS receiver and antenna since June 15, 1995.

- Shorting the antenna cable center conductor to the antenna cable shield wire results in the GPS receiver backlights going off immediately, the SOL and DR modes are immediately displayed, all processor functions stop, and all NMEA 0183 v1.5 data output stops.

Whenever the Raytheon RAYSTAR 920 GPS receiver does not have any satellite data from which to obtain a position fix, the receiver switches to the SOL and DR modes, and the satellite status information screen indicates the following: ⇒ no satellites are being tracked ⇒ no signals are present for any of the satellites ⇒ the degree of precision (DOP) is 0.0

Whenever the Raytheon 920 GPS receiver is in SOL and DR modes, the NMEA 0183 v1.5 data output contains multiple status indications of DR position data. The *Royal Majesty*'s Raytheon 920 GPS receiver and antenna functioned properly during all tests and provided temporary aural and continuous visual and electrical indications of the SOL and DR status. The electrical indications include the receiver's external alarm contact and NMEA 0183 v1.5 output data, the latter of which contains *valid*/*invalid* position data bits (A = VALID, V = INVALID) within the APA autopilot data sentence and other data sentences.

APPENDIX E

SAFETY BOARD'S URGENT SAFETY RECOMMENDATIONS

ISSUED ON AUGUST 9, 1995

M-95-26 and -27 to the U.S. Coast Guard:

> Immediately recommend that the International Maritime Organization urge its administrations to advise maritime vessel operators of the circumstances of the *Royal Majesty* grounding and to encourage the operators to review the design of their integrated bridge systems to identify potential system and operational failure modes that might result in undetected changes to the autopilot function, and develop modifications as required. (M-95-26)

> Immediately advise maritime vessel operators of the circumstances of the *Royal Majesty* grounding and urge them to review the design of their integrated bridge systems with the manufacturer to identify potential system and operational failure modes that might result in undetected changes to the autopilot function, and develop modifications as required. (M-95-27)

Although Safety Recommendation M-95-26 was not officially entered into IMO's SUBNAV-42 proceedings because of publication approval and time rules, the Coast Guard did distribute numerous copies of the recommendation, and it was discussed at several of the technical working group sessions. Consequently, Safety Recommendation M-95-26 was classified "Closed—Acceptable Alternate Action" on November 14, 1995. In response to Safety Recommendation M-95-27, the Coast Guard published a safety note in the November/December issue of the proceedings of the Marine Safety Council and also issued a "Notice to Mariners" advising them to review the operation of their integrated bridge systems to identify failure modes. As a result, Safety Recommendation M-95-27 was classified "Closed—Acceptable Action" on January 16, 1996.

M-95-28 to the International Council of Cruise Lines, the International Chamber of Shipping, the American Institute of Merchant Shipping, and the International Association of Independent Tanker Owners:

> Immediately advise members of the circumstances of the *Royal Majesty* grounding and urge those members that operate with integrated bridge systems to review the design of their integrated bridge systems for potential system and operational failure modes that might result in undetected changes to the autopilot functions.

All recipients of Safety Recommendation M-95-28 responded favorably and advised their members of the circumstances of the *Royal Majesty* grounding. For the International Chamber of Shipping, the recommendation was classified "Closed—Acceptable Action" on October 27, 1995. For the other three recipients, the recommendation was classified "Closed—Acceptable Action" on December 12, 1995.

M-95-29 to STN Atlas:

> Immediately inform customers with the NACOS 25 integrated bridge system or similar systems of the circumstances of the *Royal Majesty* grounding and review the design and implementation of their systems to identify potential system and operational failure modes that might result in undetected changes to the autopilot function.

STN Atlas acted promptly and informed all customers of the circumstances of the grounding. The recommendation was classified "Closed—Acceptable Action" on December 21, 1995.

M-95-30 to the National Marine Electronics Association:

> Immediately advise members of the circumstances of the *Royal Majesty* grounding and urge members to review their products to identify potential system and operational failure modes that might result in undetected changes to system functionality, including changes in NMEA 0183 position data validity.

The recommendation was classified as "Closed—Acceptable Action" on May 6, 1996, following NMEA's dissemination of information to all of its member companies.

APPENDIX F

PORTIONS OF COAST GUARD TRANSCRIPT OF VHF-FM RADIO TRANSMISSIONS FROM THE NANTUCKET SHOAL AREA ON THE EVENING OF JUNE 10, 1995

2042 fishing vessel (f/v) *Sao Marcos* [in English]: “Fishing vessel, fishing vessel call cruise boat.”

2043 f/v *Rachel E* [in Portuguese]: “Are you there Toluis [nickname of Tony *Sao Marcos*]?”

f/v *Sao Marcos* [in Portuguese]: “Yeah, who is this?”

f/v *Rachel E* [in Portuguese]: “It’s Antonio Pimental. Hey, that guy is bad where he is. Don’t you think that guy is wrong in that area.”

f/v *Sao Marcos* [in Portuguese]: “I just tried to call him. He didn’t answer back. He is very wrong.”

f/v *Rachel E* [in Portuguese]: “I’ve been watching him for the last half hour. He was a big contact on my radar. I picked him up 8 miles away.

[source unknown] [in English]: “Channel 16 is a distress channel and this is international, please change your channel, please change your channel.

[Portions of the remaining conversation were cut off; however, one salvageable remark in Portuguese was that f/v *Rachel E* will try to call the cruise boat.]

2045 f/v *Rachel E* [in English]: “Calling the cruise boat in the position 41 02N, 69 24W. Over.”

40 sec. Later f/v *Rachel E* [in English]: “Calling the cruise boat 41N, 69 24W. Over.”

2046 f/v *Sao Marcos* [in Portuguese]: “Maybe nobody on the bridge is paying attention.”

f/v *Rachel E* [in Portuguese]: “I don’t know. He is not going the right way.”

[Both vessels say goodbye to each other in Portuguese.]

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APPENDIX G

ABBREVIATIONS AND ACRONYMS

ARPA: automatic radar plotting aid

Boston traffic lanes: Port of Boston Traffic Separation Scheme

CFR: *Code of Federal Regulations*

DNV: Det Norske Veritas

DR: dead reckoning

FMEA: failure modes and effects analyses

GPS: global positioning system

HSI: human systems integration

ICCL: International Council of Cruise Lines

IEC: International Electrotechnical Commission

IMO: International Maritime Organization

INTERTANKO: International Association of Independent Tanker Owners

ISO: International Standards Organization

LR: Lloyd’s Register of Shipping

NACOS 25: navigation and command system

NAUT-C: optional classification notation developed by DNV

NAV: navigation (mode)

NAV1: navigation for 1-man bridge

Nav O: class notation for ocean area

Nav OC: class notation for ocean area/coastal waters

NMEA: the National Marine Electronics Association

SOL: solution

STN Atlas: STN Atlas Elektronik

TC8: Technical Committee 8 of the International Standards Organization (ISO/TC8)

TC80: Technical Committee 80 of the International Electrotechnical Commission (IEC/TC80)

W1: Watch 1, highest class notation in NAUT-C

WG9: working group belonging to the IEC/TC80