National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: August 9, 1995

In reply refer to: M-95-26 and -27

Admiral Robert E. Kramek
Commandant
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Washington, D.C. 20593-0001

About 2225,[1] on June 10, 1995, the Panamanian passenger ship *Royal Majesty* grounded in about 11 feet of water[2] on Rose and Crown Shoals about 10 miles east of Nantucket Island, Massachusetts. The vessel, with 1,509 persons on board, was en route from St. Georges, Bermuda, to Boston, Massachusetts, when the accident occurred. The grounding occurred in an area of hard sand that caused the vessel to be trimmed about 10 feet by the stern and to assume a 3.5° starboard list. The vessel's engineering and habitability systems, however, remained fully operational.

Initial attempts to free the vessel were unsuccessful. A plan to evacuate passengers to ferries and transport them ashore was considered but later postponed because of deteriorating weather and sea conditions.

At 2154 on June 11, the *Royal Majesty*, with the aid of five tugs, was refloated and escorted to a deep water anchorage off Chatham, Massachusetts, where initial damage surveys were conducted. Although the subsequent inspection by divers revealed damage to the vessel's double bottom fuel oil tanks, no penetration or cracking of the hull was detected. The vessel was then given permission by the U.S. Coast Guard to proceed to Boston. At 1535 on June 12, the vessel safely moored alongside the Black Falcon Passenger Terminal, cleared customs, and began disembarking its passengers.

[1] Eastern daylight times based on a 24-hour clock.

[2] The *Royal Majesty* was drawing 19 feet 6 inches of water at the time of the grounding.

There were no injuries or deaths as a result of this accident. Lost revenue and damage to the vessel, however, were substantial.[3]

The *Royal Majesty* was fitted with an integrated bridge system containing an STN ATLAS Elektronik Navigation Command System (NACOS 25).[4] The NACOS 25 was designed to assist bridge officers with voyage planning, navigation, shiphandling and collision avoidance tasks.

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 vessel's Global Positioning System (GPS)[5] and LORAN-C[6] units, was capable of automatically steering the vessel along a predetermined route. When engaged and operating in the "Navigation 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 conditions. According to the *Royal Majesty's* bridge officers, the NACOS 25 autopilot was engaged and operating in the "Navigation Mode" between the time the vessel departed St. Georges, Bermuda, (1400 June 9, 1995) and the time of the accident more than 32 hours later.

At the time of the accident, the NACOS 25 autopilot was configured with two input ports that accepted navigation data in NMEA 0183[7] format. A Raytheon RAYSTAR 920 GPS unit and a Raytheon RAYNAV 780 LORAN-C unit were connected to the ports and provided data to the autopilot in NMEA 0183 v1.5 format. However, the NACOS 25 autopilot was configured such that during operation it could use and display position data from only one of these external position inputs at a time, either from the GPS or from the LORAN-C. The NACOS 25 autopilot could not look at both position inputs simultaneously, nor could both sets of position data be displayed to the bridge officers simultaneously on the NACOS 25 display.

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[3] The Safety Board's investigation of this accident is continuing.

[4] According to STN ATLAS Elektronik, 260 such units have been sold worldwide with over 200 being operational. (*Safety At Sea*, June 1995, p. 36.)

[5] A satellite-based radio navigation system designed to provide global, 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.

[6] A radio-based navigation system designed to provide position data along the coasts of the United States. The accuracy of the system is based on the LORAN-C unit's ability to receive, identify, and measure radio signals from a series of land-based LORAN stations.

[7] National Marine Electronics Association 0183 is an industry standard electronic signal specification that defines how data are to be transmitted from a navigation device. The standard allows the integrated use of different manufacturer navigation devices and the design and manufacture of compatible modular marine electronics.

The autopilot was also programmed to calculate its own dead reckoning (DR)[8] position to provide a comparison with the position data provided by the GPS or LORAN-C. If the autopilot DR-derived position and the GPS or LORAN-C positions were within 200 meters of each other,[9] the autopilot considered the GPS or LORAN-C data valid, accepted the data, and made the appropriate course corrections. If, however, the two positions were more than 200 meters apart, the autopilot was programmed to sound a loud alarm and present a visual indication on the NACOS 25 display that a position discrepancy had been detected that required the bridge officers' immediate attention.

The GPS unit installed on the *Royal Majesty* had been designed as a stand-alone navigation device in the mid- to late 1980s when navigating by DR was common and before the Department of Defense declared the GPS satellite system fully operational. To compensate for the possible lack of satellite data, the manufacturer designed a speed and gyro heading DR data input port into the GPS unit 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 are derived from DR calculation rather than satellite-based position data.[10] When this occurs, the GPS:

- issues a series of aural chirps similar to a wristwatch alarm lasting less than 1 second;
- continuously displays the symbols SOL[11] and DR on its screen;
- changes the state of a transmitted data bit from valid to invalid, indicating that valid satellite-based position data are no longer being transmitted (via the NMEA 0183 v1.5 connection); 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.).

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[8] Dead reckoning is a means of navigating whereby an initial position is established, and from that point on the position is estimated, over time, using data input from the vessel's speed log and gyro. Dead reckoning does not account for the effects of wind, current, or sea conditions.

[9] The NACOS 25 autopilot has an OFF TRACK alarm feature that allows the operator to set this position comparison limit anywhere between 10 and 990 meters. It was set at 200 meters in this case.

[10] RAYSTAR 920 DR mode capability requires an optional DR interface box along with selection of "HYBRID" mode on the RAYSTAR 920. The *Royal Majesty*'s RAYSTAR 920 was configured this way.

[11] SOL (solution) is meant to indicate that the GPS satellite position solution is invalid or not available.

During the Safety Board's investigation, staff of Majesty Cruise Lines, owner of the *Royal Majesty*, indicated that after the accident they found the shield wire portion of the GPS antenna cable separated from the connection at the antenna. Testing has shown that such a failure would result in the unit transmitting DR-derived position data instead of satellite-based position data to the NACOS 25 autopilot.[12] Because the GPS used the same gyro heading and speed inputs as the NACOS 25 autopilot to calculate its position, the GPS DR-derived position data were virtually identical to that of the DR-derived position data computed by the NACOS 25 autopilot. Therefore, the position error between the two would be negligible and the NACOS 25 OFF TRACK position alarm would not be activated.

Because DR-derived position data do not account for the effect of wind, current, or sea conditions, errors were introduced into the system that compromised the ability of the NACOS 25 autopilot to follow the vessel's programmed track. Over time, the difference between the vessel's actual position and the DR-derived latitude and longitude data provided by the GPS and the NACOS 25 increased to more than 17 miles. The Safety Board has not yet determined exactly when the GPS defaulted to the DR mode except that it probably occurred many hours before the grounding. The investigation has revealed, however, that the reversion of the GPS to the DR mode and its effect on the NACOS 25 autopilot were not detected by the *Royal Majesty's* bridge officers.

The following factors may have contributed to the failure of the bridge officers to recognize that the GPS unit had defaulted to the DR mode:

- the GPS unit was mounted behind a wall on a chart table about 15 feet behind the navigation console, in an area where the bridge officers operating the vessel were not likely to hear or see the unit's internal DR alarm and annunciators;

- the GPS system's remote alarm switch was not connected to any form of external alarming device;

- the autopilot software was not designed to check the valid/invalid data bit that accompanies the position data in the NMEA 0183 data stream.

The bridge officers of the *Royal Majesty* had several means, other than the GPS, by which to determine or evaluate their position. Their other resources included the Raytheon LORAN-C navigation unit, three radars, a radio direction finder (RDF), and a fathometer. However, at this point in the Safety Board's investigation, it appears that the bridge officers relied primarily on the GPS for

[12] The exact mode of antenna connection failure is still under investigation.

navigating the vessel and did not effectively cross check with these other sources of position information. After the accident, the bridge officers checked the position shown by the LORAN-C navigation unit, and found that it correctly showed the vessel at the position on the shoal where it had run aground. It was also determined that prior to the accident, the vessel's radars had all been set on the 6-mile range scale. As a result, the bridge officers were unaware how close they were to Nantucket (about 10 miles) and Rose and Crown Shoals. The NACOS 25 depth alarm function could also have been used to detect the abnormally shallow depths that were encountered during the 3 hours of the vessel's operation preceding the grounding.

Following the accident, the Raytheon GPS unit was removed by Majesty Cruise Lines for testing and a Northstar GPS unit was installed. Although the Raytheon and Northstar GPS units both provide data to the NACOS 25 autopilot in NMEA 0183 format, the units have different features and operational characteristics. The Northstar GPS unit does not have DR capability by design, thus preventing the autopilot from receiving DR-based position data from its GPS source. Additionally, the Northstar GPS nulls all position data within the NMEA 0183 data stream when it loses satellite data or otherwise cannot calculate a GPS position. Any loss of satellite-based position data from the Northstar GPS should therefore result in an immediate OFF TRACK alarm from the NACOS 25 autopilot.

The failure of the *Royal Majesty's* NACOS 25 autopilot to sound an alarm when the GPS unit reverted to DR mode resulted in a "silent" failure mode within the integrated bridge system. Aeronautical and aerospace design safety practices typically require the implementation of system redundancy and analysis of potential failure modes. The performance of failure modes and effects analyses (FMEAs) of *Royal Majesty's* integrated bridge system would likely have disclosed the potential for the sequence of events leading to the grounding of the vessel. This could have highlighted the need for (1) multiple independent GPS system inputs to the autopilot for comparison of position, (2) continuous audio alarms by the GPS unit in the event of a system failure, (3) simultaneous autopilot monitoring of the GPS and Loran-C positions for large discrepancies, or (4) autopilot interrogation of the GPS unit's NMEA 0183 valid/invalid position data bit and the provision for alerting the bridge officers when the position data are invalid.

The Safety Board's preliminary investigation into the grounding of the *Royal Majesty* raises concerns about the safety of the world's maritime fleet and the passengers and crew aboard these vessels, as well as the potential damage to the environment. These concerns warrant the issuance of urgent safety recommendations relating to potential failures of integrated bridge systems.

Therefore, the National Transportation Safety Board recommends that the United States 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. (Class I, Urgent Action) (M-95-26)
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> 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. (Class I, Urgent Action) (M-95-27)

The Safety Board has also issued urgent safety recommendations regarding the *Royal Majesty* grounding to the International Council of Cruise Lines, the International Chamber of Shipping, the American Institute of Merchant Shipping, the International Association of Independent Tanker Owners, the National Marine Electronics Association, and STN ATLAS Elektronik.

Chairman HALL, Vice Chairman FRANCIS, and Member HAMMERSCHMIDT concurred in these recommendations.

By: Jim Hall
Chairman