Capsizing of U.S. Small Passenger Vessel *Lady D* Northwest Harbor, Baltimore, Maryland March 6, 2004

Marine Accident Report

NTSB/MAR-06/01

PB2006-916401
Notation 7679A

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National Transportation Safety Board
490 L'Enfant Plaza, S.W.
Washington, D.C. 20594

National Transportation Safety Board. 2006. ***Capsizing of U.S. Small Passenger Vessel*** **Lady D,** ***Northwest Harbor, Baltimore, Maryland March 6, 2004.*** **Marine Accident Report NTSB/MAR-06/01. Washington, DC.**

Abstract: On March 6, 2004, the small passenger vessel *Lady D,* a pontoon water taxi with 2 crewmembers and 23 passengers on board, was en route from Fort McHenry to Fells Point, Maryland, when it encountered a rapidly developing storm with high winds. The pontoon vessel began to roll in the waves and eventually continued over onto its starboard side and capsized. Responders were able to rescue or recover all but 3 occupants of the *Lady D* and transport them to area hospitals within an hour of the accident. The bodies of the remaining victims were recovered from the waterway on March 14 and 15. As a result of this accident, 5 passengers died; 4 passengers suffered serious injuries; and 12 people sustained minor injuries.

Major safety issues discussed in this report include passenger weight criteria for stability assessment; pontoon vessel stability standards; and policies and procedures pertaining to weather operations.

As a result of its investigation of this accident, the Safety Board made safety recommendations to the U. S. Coast Guard.

Contents

Abbreviations and Acronyms

ASOS	Automated Surface Observing System
AWOS	Automated Weather Observing System
BCFD	Baltimore City Fire Department
BCPD	Baltimore City Police Department
BWI	Baltimore-Washington International Airport
CAMI	Civil Aerospace Medical Institute
CESM	Cold Exposure Survival Model
CFR	*Code of Federal Regulations*
COI	certificate of inspection
dBZ	decibels of Z (where Z = energy reflected back to radar)
EMS	emergency medical service
ICAO	International Civil Aviation Organization
ISO	International Organization for Standardization
LCM-8	mechanized landing craft
LWX	Sterling weather radar station
MSC	Marine Safety Center
MSO	Marine Safety Office
NCEP	National Centers for Environmental Prediction
NHS	National Historic Seaport of Baltimore
nm	nautical mile
NOAA	National Oceanic and Atmospheric Administration
NPRM	notice of proposed rulemaking
NVIC	navigation and vessel inspection circular
NWR	NOAA Weather Radio
NWS	National Weather Service
OCMI	Officer-in-Charge, Marine Inspection
PSST	pontoon simplified stability test
SAR	search and rescue
SST	simplified stability test
TDWR	terminal Doppler weather radar
UHF	ultrahigh frequency
VHF	very high frequency

WFO	weather forecast office
WSR-88D	weather surveillance radar-88 Doppler

Executive Summary

On March 6, 2004, the small passenger vessel *Lady D*, a pontoon water taxi with 2 crewmembers and 23 passengers on board, was en route from Fort McHenry to Fells Point, Maryland, when it encountered a rapidly developing storm with high winds. The pontoon vessel began to roll in the waves and eventually continued over onto its starboard side and capsized. Personnel from the Naval Reserve Center Baltimore, a Navy training installation adjacent to Fort McHenry, witnessed the capsizing, called 911 to report the accident, and then launched a vessel to the scene to render assistance. Responders were able to rescue or recover all but 3 occupants of the *Lady D* within an hour of the accident. The bodies of the remaining victims were recovered from the waterway on March 14 and 15. As a result of this accident, 5 passengers died; 4 passengers suffered serious injuries; and 12 people sustained minor injuries. Vessel damage was estimated at $35,000.

The Safety Board's investigation of this accident identified major safety issues in the following areas:

- Passenger weight criteria for stability assessment;
- Pontoon vessel stability standards; and
- Policies and procedures pertaining to weather operations.

The National Transportation Safety Board determines that the probable cause of the capsizing of the pontoon-style small passenger vessel *Lady D* was its lack of intact stability, which was insufficient to withstand the strong winds and waves that the boat encountered. The lack of intact stability was caused by overloading, which resulted from a combination of the following:

- The *Lady D* was erroneously granted sister status by the U.S. Coast Guard to a pontoon vessel with different design characteristics;
- The Coast Guard certificated the *Lady D* to carry too many people as a result of an inappropriate stability test on the vessel to which it was granted sister status; and
- The Coast Guard's regulatory stability test standards on which the *Lady D*'s passenger allowance was based use an out-of-date average passenger weight.

As a result of this investigation, the Safety Board makes recommendations to the U.S. Coast Guard.

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Factual Information

Accident Narrative

Taxi Operations at Baltimore Harbor

In March 2004, Seaport Taxi was one of two water taxi companies servicing the harbor area in Baltimore, Maryland. Depending on the weather and time of year, the company activated the number of vessels in its fleet necessary to handle anticipated customer demand and assigned them to one of two established routes: an inner loop, which was between Harbor Place and Fells Point, Maryland, and an outer loop, which was between Fells Point and Fort McHenry. (See figure 1.) The water taxis, all pontoon-style vessels, transported passengers to local maritime attractions and to other points authorized by the City of Baltimore.[1]

According to the office manager for Seaport Taxi, when she arrived at work on March 6, "the weather was very nasty; it was raining a lot." A small craft advisory, issued the previous day by the National Weather Service (NWS) Baltimore-Washington forecast office, was still in effect for all of Chesapeake Bay, including Baltimore's Inner Harbor.[2] Throughout the day, the Seaport Taxi office manager had her radios on to monitor message traffic from the company taxis and to listen for National Oceanic and Atmospheric Administration (NOAA) weather alerts.

Seaport Taxi was also a subscriber to WeatherBug®, a Web-based source of neighborhood weather, severe storm alerts, and radar and camera images. The office manager said she listened throughout the day for the distinctive "beep" emitted by her office computer when WeatherBug® issued a bulletin, but heard none. She stated that, by about 1400, the sun had come out, and it was "pretty nice." Later that afternoon, however, she started hearing raindrops striking a sign in the marina and looked north out her window. She said that she noticed that the sky was "very black" and that there was lightning to the north.

[1] At the time of this accident, Living Classrooms Foundation (Living Classrooms), a nonprofit organization headquartered at Baltimore's Inner Harbor, owned Seaport Taxi. Information related to operating policies and practices appears later in this report, under "Operational Information."

[2] A small craft advisory for mariners is issued by the NWS when sustained winds and frequent gusts of 18 to 33 knots (21 to 38 miles per hour) persist for 3 or more hours.

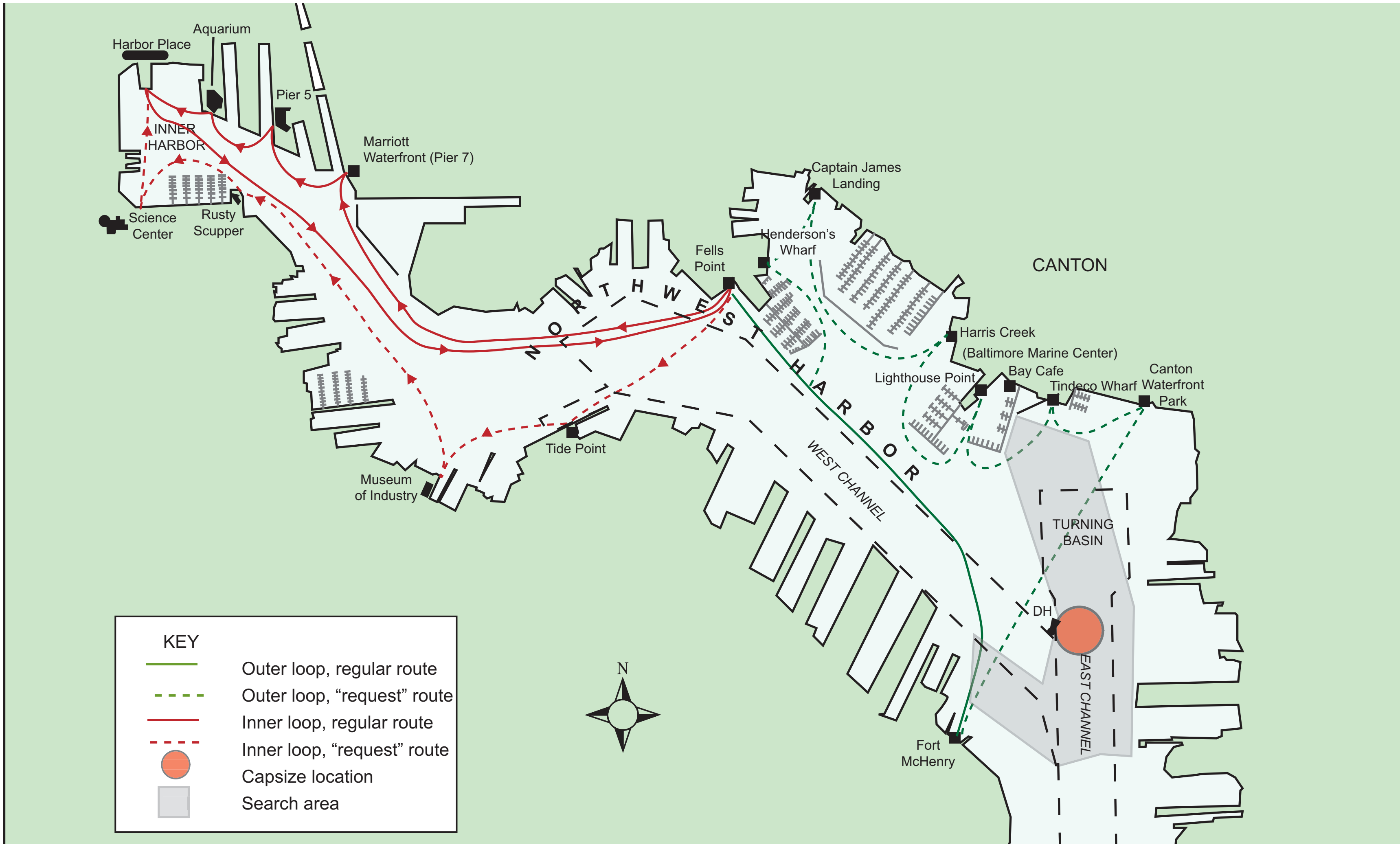

Figure 1. Each Seaport Taxi vessel followed one of two round-trip routes unless passenger traffic warranted otherwise. The inner loop between the Inner Harbor complex and Fells Point included two regular stops and two "request" stops, meaning passengers could ask to disembark at these sites or customers on shore could telephone or radio to be picked up there. The outer loop route, which originated at Fells Point, had one regular stop at Fort McHenry and six request stops in the Canton area.

About 1555, the office manager overheard a radio communication from the company's senior captain on the water (senior captain) alerting the vessel operators on duty that a storm was coming through and to "use their discretion about tying up." She said that she then checked the Doppler weather radar images on her computer, which indicated that a storm north of the area was moving south-southeast.[3] She then radioed the fleet to advise the masters that Doppler images showed that the heaviest parts of the storm were north and south of their area and that it looked as if their area "might see a little sprinkle"; however, "All of a sudden, it was a torrential downpour."

Events On Board the Lady D

About 1100 on March 6, Seaport Taxi had placed the *Lady D* (figure 2) into routine service, shuttling passengers back and forth on the outer loop between Fells Point and Fort McHenry.

Figure 2. The U.S. small passenger vessel *Lady D* (above), an 8-foot-wide by 36-foot-long commercial pontoon boat, was certificated by the U.S. Coast Guard to carry 25 people. The process by which the *Lady D's* allowable load was determined is discussed in the "Vessel Information" section of this report.

[3] Various news and weather websites obtain Doppler image and other information from the NWS to provide to their customers; however, because of the time taken to capture and display the images on the websites, typically from 3 to 10 minutes, the information displayed on the office manager's computer did not reflect current conditions.

About 1545, the *Lady D*, with an operating crew of a master and a mate, arrived at fireboat pier 1 next to Fort McHenry[4] for the express purpose of transporting visitors at the fort back to Fells Point. As soon as the water taxi docked, Seaport Taxi's fort coordinator, an employee responsible for managing the embarkation and debarkation of visitors, said that he opened the gate at the end of the pier, permitting waiting passengers to proceed to the boarding area. The *Lady D*'s certificate of inspection (COI), issued by the Coast Guard,[5] limited the vessel's occupancy to 25 persons. The mate counted the people as they sat down on one of the two benches that lined either side of the vessel until 23 passengers had boarded. Two couples were not permitted to board after the vessel was at maximum capacity. The master said that he verified the mate's passenger count before departing. As the commercial pontoon taxi backed away from the fireboat pier about 1554, the master sent out a broadcast message to the fleet and to the fort coordinator that the *Lady D* was departing for Fells Point with 25 persons on board.[6] The passengers included 3 children, ages 6, 7, and 8, and 20 adults, ages 23 to 60.[7]

The master and the mate indicated that the mate gave a safety briefing as they were departing.[8] Most passengers indicated that they had received a safety briefing on previous voyages that day; however, none recalled receiving a safety briefing at the onset of the return voyage from the fort to Fells Point.

The master said that earlier that afternoon, about 1400, the winds were about 10 to 15 knots, an estimate that he had based on "the way flags appeared on their poles." He noted that as he was backing away from the pier, "the wind really started picking up." He also observed some dark clouds west of the city. Neither the master nor the mate stated that he observed lightning. According to passengers and shore witnesses, it began to rain as the boat was departing, and then the weather began to deteriorate rapidly, with increasing winds and lightning. Shortly thereafter, the *Lady D* master received a radio communication from the senior captain who had heard thunder[9] and whose boat began to

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[4] The Fort McHenry pier was damaged, and Seaport Taxi had arranged with the Baltimore City Fire Department (BCFD) to permit fort visitors to embark and disembark at the nearby fireboat pier.

[5] The Coast Guard certificates passenger vessels for commercial operation, documenting operating requirements and restrictions in the vessel's COI.

[6] Federal regulations at Title 46 *Code of Federal Regulations* (CFR) Part 185.504, "Passenger Count," require, in part, that a vessel master keep a correct, written count of all passengers that embark on the vessel and that, before the vessel sails, this count be communicated verbally or in writing, and available ashore at the vessel's normal berthing location or with a representative of the owner or operator of the vessel. In this instance, the Seaport Taxi fort coordinator maintained the passenger count.

[7] From interviews and hospital records, the Safety Board determined that the average weight of the children was 55 pounds and the average weight of the adults was 184 pounds, which equated to an average occupant weight of 168.4 pounds.

[8] Federal regulations at 46 CFR 185.506 require, in part, that, before getting underway on a voyage or as soon as practicable thereafter, the master will ensure that "suitable public announcements are made informing all passengers" where emergency exits and lifejackets are located and how lifejackets should be donned.

[9] No area witnesses who were interviewed, including Seaport Taxi personnel, passengers, and Baltimore police, recalled seeing lightning before 1600. Reports issued by StrikeNet, an online lightning verification service, indicate that a lightning strike was recorded 6.6 miles north-northwest of Baltimore at 1551. After that, multiple lightning strikes were recorded at 1555, including one 5.5 miles west of the accident site; one 8.5 miles northwest of the area; and one 8.1 miles west-northwest of the area.

be buffeted by winds while en route from Harbor Place to Fells Point. The senior captain advised all vessels in service to tie up until the storm passed. The *Lady D* master next received a radio report from the Seaport Taxi office manager advising that radar indicated that the heaviest precipitation probably would not affect their area. The *Lady D* master then radioed the senior captain advising that he had already left Fort McHenry. Upon learning that the *Lady D* had departed, the senior captain suggested that its master divert to the Baltimore Marine Center or Henderson's Wharf. (See figure 1.)

Meanwhile, as the pontoon vessel moved farther out into the channel, occupants said that the boat began to roll in the waves. Safety Board investigators received varying accounts of how the *Lady D* handled in the wind. Some passengers reported that the wind was initially off the pontoon vessel's port side but that the wind direction began to shift counterclockwise. The mate stated that the master initially held the boat into the wind as the gusts intensified; however, "The wind then picked up even stronger and blew him off, threw him like in a spiral." The master also stated that he had difficulty handling the boat once the wind picked up and the waves increased. He said that he could not even turn in the direction of the Baltimore Marine Center and that he was "almost pushed out" to an area "opposite the Bay Cafe"; however, "I couldn't even get there."

Personnel at Naval Reserve Center Baltimore, located near Fort McHenry, were watching the *Lady D* as the water taxi was attempting its transit and was being buffeted by the wind and waves. They said that, at one point, the vessel appeared to be heading south.

One passenger sitting on the port side of the *Lady D* said, "The wind came across our back, and keeled us up…[and] the people on the starboard side immediately, out of instinct, came over to try and right the boat, and it helped some. The [master] brought the boat around into the wind, to level the boat out." Meanwhile, the mate asked the passengers on the starboard side to return to their bench. Passengers said that he nervously joked that the lifejackets were under the benches. Moments later, the vessel heeled to starboard again, continued over onto its starboard side, and capsized. Some passengers estimated that the capsizing sequence took only a few seconds.

Escape and Rescue

Immediately after the capsizing at 1558, the personnel at the Naval Reserve Center Baltimore who had been watching the *Lady D* called 911 to report the accident. Detachment 106, Fleet and Industrial Supply Center Norfolk, which was on drill status at the center, then launched a mechanized landing craft (LCM-8) with 19 reservists on board to the accident site. The LCM-8 was the first vessel on scene to render assistance, arriving about 1606. Meanwhile, the 911 call was relayed to the BCFD; however, a marine firefighter at the BCFD fireboat station had witnessed the accident and already alerted personnel at the station. The BCFD dispatched a 30-foot fire rescue boat to the scene to render assistance. Soon after, Baltimore City Police Department (BCPD) boats joined the other rescue vessels at the site of the capsizing. By 1603, the BCFD dispatcher had ordered various marine and shore-based assets totaling 43 rescue and medical personnel to respond during the initial response. In addition, upon determining where the accident voyage had originated, the BCPD dispatched patrol officers to Fort McHenry to determine from Seaport Taxi's fort coordinator how many people had been on board the *Lady D*.

Seaport Taxi sent its fleet captain and the senior captain to the area to assist. In addition, the water taxi company contacted Coast Guard Sector Baltimore, which had learned of the capsizing when watchstanders overheard message traffic about the accident while monitoring VHF (very high frequency) channel 16. The Coast Guard contacted the BCFD and, after being briefed about the capsizing, dispatched search and rescue (SAR) assets to the scene.

Meanwhile, the *Lady D's* survivors said that after the pontoon boat overturned, water quickly began to fill the cabin. Several survivors said that they had problems getting out of the vessel. The *Lady D* had two doors: a sliding door at the bow that slid to the side and a hinged door at the stern that swung open. A passenger seated near the bow said that he tried to exit the door there; however, he could not get it to slide open. Another passenger who was seated near the stern door said that he thought that he exited through the back door because while swimming to the water's surface, he struck the outboard engine. One passenger who was seated amidships was able to escape through a window opening. He later stated, however, that it never occurred to him to use a door, which should have been "an obvious choice."

The *Lady D* had 12 slider windows, six along the port side of the vessel and six along the starboard side. (See figure 2.) Each slider window had one 24-inch-wide fixed sash and one 24-inch-wide sliding sash. One passenger said that he kicked on the window to get it to open. Another passenger said that he tried to open a window, but it seemed to be locked.[10] He then noticed that the man next to him slid a window to the side to open it, whereupon he slid open his own window. He said that by this time, he could not see anything in the murky water. He felt a "sensation," but was not sure whether it was water pushing against him or whether "the window just … caved in…." He then felt his way out of the boat. A female passenger also stated that while swimming down in the overturned deckhouse to find an exit, she felt and pushed on a window, only to have it "float away," which led her to believe that it was no longer attached to the boat.

Navy reservists said that once the LCM-8 reached the water taxi, which was floating upside down, they observed a "lot of lifejackets" floating around the boat. All but two survivors had climbed atop the pontoons or the underside of the deck. The remaining two survivors were still in the water but holding onto the pontoon vessel. None of the *Lady D* occupants had donned a lifejacket; however, one of the people in the water had grabbed hold of one. The *Lady D*'s master later told investigators that he thought he was not going to be able to escape the vessel; however, when he saw a lifejacket floating inside the deckhouse, he grabbed it and held onto it as he pushed toward "a light." He said that as he exited the boat, the lifejacket pulled him up to the water's surface.

[10] The Seaport Taxi director said that originally locks had been on the windows; however, over time and with continued use, the locks had broken off, and at the time of the accident, no window on the *Lady D* could be locked.

A few reservists, wearing their own lifejackets, jumped into the water to assist the accident victims. One reservist who entered the water without his lifejacket subsequently donned one of the *Lady D*'s lifejackets during the rescue effort to ensure that he remained afloat in the cold water. The reservists tied their craft to the water taxi and escorted the survivors onto the LCM-8. Upon learning that passengers were still trapped inside the water taxi, reservists untied the lines holding the vessels together and lowered the LCM-8's loading ramp into the water and used it as a lever to raise one side of the capsized water taxi. Witnesses said that this action freed three trapped passengers, including two adult women and a little girl.

Responders to the capsizing retrieved and transported 22 vessel occupants to shore within 30 minutes of the *Lady D*'s overturning. Of the recovered passengers, 2 died at the hospital: the first victim within 2 hours of the capsizing and the second victim within 72 hours. A third passenger continues to be under long-term medical care. The remaining survivors were treated by local hospitals for minor injuries and released.

Three passengers were not found on the day of the accident. Their bodies were located and recovered from the bottom of the harbor about 1 week after the accident.

Injuries

The injuries sustained by the *Lady D*'s crew and passengers, shown in table 1, are categorized according to the injury criteria of the International Civil Aviation Organization (ICAO). The Safety Board uses the ICAO injury criteria in most of its accident reports. A discussion of the injuries appears later in this report, under "Medical and Pathological Information."

Table 1. Injuries sustained by the *Lady D* occupants

Injury Type	Crew	Passengers	Total
Fatal	0	5	5
Serious	0	4	4
Minor	2	10	12
None	0	4	4
Total	2	23	25

Title 49 CFR section 830.2 defines a *fatal* injury as: any injury that results in death within 30 days of the accident. It defines *serious* injury as that which requires hospitalization for more than 48 hours, commencing within 7 days from the date the injury was received; results in a fracture of any bone (except simple fractures of fingers, toes, or nose); causes severe hemorrhages, nerve, muscle, or tendon damage; involves any internal organ; or involves second or third degree burns, or any burn affecting more than 5 percent of the body surface.

Damages

Seaport Taxi elected not to repair and return the *Lady D* to service following this accident. A company spokesperson estimated the value of the pontoon-style small passenger vessel at $35,000. Additional information about the damage to the *Lady D* appears later in this report, under "Wreckage."

Crew Information

Regulatory Requirements

In certificating a small passenger vessel for commercial operation, the Coast Guard determines the number of crewmembers needed and their required competencies by considering, among other things, the size of the vessel, its route, the type and horsepower of the vessel's propulsion machinery, the number of passengers the vessel may carry, the type and location of lifesaving equipment installed on the vessel, and the hazards specific to the route and service. In the case of the *Lady D*, its COI stipulated that the pontoon taxi have one licensed crewmember: the master. According to Seaport Taxi officials, they usually assigned two crewmembers to each vessel, a licensed master and an unlicensed mate. On the day of the accident, the *Lady D* had two licensed masters on board, one serving as captain and the other serving as mate.

Master

General. The master, age 74, had taken up boating in 1995. The following year, he bought his first boat, a diesel-powered 46-foot Bayliner. In July 2001, he purchased a gasoline-powered 34-foot Sea Ray. Concurrently, he took several courses in maritime education, including a 48-hour boating course conducted by the U.S. Coast Guard Auxiliary, several courses conducted at the Virginia Maritime Institute, a course on twin-engine boat handling conducted by the Power Boat Division of the Annapolis Sailing School, and courses conducted at the Baltimore Community College.

On April 30, 2002, the Coast Guard issued him a U.S. Merchant Marine Officer license authorizing him to serve for 5 years as a master of steam or motor vessels of not more than 50 gross registered tons (domestic tonnage) upon inland waters. The license also authorized him to engage in commercial assistance towing.

In July 2002, he was hired by Seaport Taxi to work as a part-time captain, his first job in the maritime industry. After completing Seaport Taxi's orientation training and boat-handling exercise,[11] he was assigned to the *Lady D* and operated that vessel thereafter, generally on weekends but sometimes full-time during the peak season.

The Seaport Taxi director indicated that the master was "very, very good at handling" a vessel the size of the *Lady D*, particularly when maneuvering in tight quarters such as the 20-foot fairway,[12] which can be "a little bit of a challenge in the wind." Company officials indicated that they had not trained the *Lady D* master to operate the larger vessels in Seaport Taxi's fleet. The fleet captain stated that the decision not to qualify the *Lady D* master on larger boats had to do with staffing needs and the expense of training. He said that the company had plenty of masters to drive the larger boats and that qualifying the *Lady D* master on the larger vessels meant that the company would have to

[11] For additional information about the Seaport Taxi training program, see "Operational Information."

[12] In nautical terms, "fairway" refers to either the navigable channel or the usual course that a vessel travels through a harbor or coastal waters. In this case, the Seaport Taxi director is referring to the waterway between the piers that the pontoon vessel traveled to reach its docking place.

take a large boat out of commercial service when the master was available, which was usually the weekends when passenger traffic was greater. The fleet captain also stressed that the *Lady D* master operated his boat well.

Medical. The master told Safety Board investigators that he took no prescription drugs. He said, however, that he had completed taking a prescribed course of antibiotics about 10 to 12 days before the day of the accident. He indicated that he had worn a hearing aid to discriminate sounds for about 3 years. Medical records indicate that his eyesight was 20/38, corrected to 20/20.

Work/Rest History. The master indicated that he normally awoke each day at 0600 and went to bed at 2230. As noted earlier, he typically worked weekends. He indicated that he did not change his routine before the accident. He said that he went to bed on Thursday and Friday, March 4 and 5, about 2215. On Saturday, March 6, the day of the accident, he awoke at 0645 and reported to work at 0930, a half hour before his shift was scheduled to begin.

Mate

General. The mate, age 55, had completed a November 4, 1997, boating course conducted by United States Power Squadrons, a nonprofit educational organization whose districts teach sail and power boating classes. In May 2003, Seaport Taxi hired him as a mate in a "seasonal/contractual hire" status, and he originally worked about 15 hours per week. In mid-2003, Seaport Taxi granted the mate limited authorization to learn boat-handling skills while he studied for his master's license. The company form, "Authorization to Operate Seaport Taxi Vessels While in Training for Captains License," required the master of the respective vessel to supervise the mate and be responsible for his actions. The mate was not allowed to operate the vessel with passengers on board until the master considered him competent to do so.

When the mate applied for his master's license, Seaport Taxi forwarded to the Coast Guard Regional Examination Center in Baltimore a "Sea Time Letter," which indicated that the mate had operated a vessel[13] for 52 underway days of approximately 8 hours each between May and October 2003 on five vessels in the company fleet.

On November 20, 2003, the Coast Guard issued the mate a U.S. Merchant Marine Officer license authorizing him to serve for 5 years as a master of steam, motor, or auxiliary sail vessels of not more than 50 gross registered tons (domestic tonnage) upon inland waters. He was also authorized to engage in commercial assistance towing. The license carried a vision waiver: "Corrective lenses to be worn with spare glasses carried on board."

Medical. The mate told Safety Board investigators that he took cymetadine (Zantac type) for acid reflux disease.

[13] Until the Coast Guard issued the mate a master's license, he could operate a vessel only under the supervision of a licensed master.

Work/Rest History. The mate said that he awoke at 0730 on Thursday, March 4, performed maintenance from 0930 to 1730, and was asleep by 2400. The following day, he did not work and was at home attending to his own boat. The night before the accident, he was asleep by 2300. On Saturday, he awoke at 0730 and was at work by 0915.

Vessel Information

Regulatory Requirements for Small Passenger Vessels

Federal regulations pertaining to commercial pontoon vessels are contained in 46 CFR Subchapter T, "Small Passenger Vessels (Under 100 Gross Tons)."[14] Subchapter T stipulates that to operate a small passenger vessel, the owner/operator must have various programs and policies, maintain various documents, and install and maintain various navigation and radio equipment, lifesaving equipment, and firefighting equipment on that vessel. The Federal regulations also stipulate that an existing vessel must comply with the intact stability[15] regulations applicable to it as of March 10, 1996.

The Coast Guard official with the oversight responsibility for ensuring compliance with marine safety standards, including the requirements in Subchapter T, is the Officer-in-Charge, Marine Inspection (OCMI) at each Marine Safety Office (MSO), which is a local Coast Guard office having jurisdictional authority for a specific area. Any restriction or contingency that the OCMI deems necessary for the safe operation of a vessel is listed on its COI.

The Lady D

Vessel History. The *Lady D* was built in 1996 for Baltimore Harbor Shuttle, LLC, by the boat builder formerly known as Susquehanna Santee Boatworks,[16] headquartered in Pennsylvania. The vessel was the third in a design series of four commercial pontoon boats measuring 36 feet long by 8 feet wide. Because the *Lady D*'s date of build was March 18, the pontoon boat was required to comply with Subchapter T regulations for new vessels that were effective on March 10, 1996.

The first boat in the series, the *Fells Point Princess*, was built by an individual in his backyard, and the following three in the series—the *Raven*, the *Lady D*, and the *Misty Harbor II*—were built by Susquehanna Santee Boatworks. After the *Lady D* was launched

[14] Subchapter T was promulgated in 1957 as a result of Public Law 519, which was enacted by the U.S. Congress following the capsizing of the M/V *Pelican* off Long Island, New York. The small commercial fishing vessel, which was designed to safely accommodate 30 persons, was carrying 64 people when it capsized in heavy seas. Because of the vessel's overloaded condition, the sea state, and the failure of the boat's occupants to don lifejackets, 45 people died.

[15] Stability is the tendency of a vessel to remain upright or its ability to return to the normal upright position when heeled by the action of weight movements, waves, wind, and so forth.

[16] In October 1998, Susquehanna Santee Boatworks was purchased by another company, which assumed its name and assets, including files on the *Lady D*. Thus, the company named as a party in this investigation was not the builder of the *Lady D*.

in March 1996, Baltimore Harbor Shuttle operated it as a water taxi in Baltimore Harbor. In 2000, Living Classrooms, the parent company of Seaport Taxi, purchased the Baltimore Harbor Shuttle fleet, and the *Lady D* continued to operate in the Baltimore Harbor area, primarily on Seaport Taxi's outer loop between Fells Point and Fort McHenry.

Vessel Construction and Design. The vessel's pontoons, hull, and deckhouse (figure 2) were constructed of marine-grade aluminum. The hull consisted of two cylindrical pontoons connected by an I-beam framework and deck structure. The pontoons were constructed in seven sections, with a transverse bulkhead between each section. The deckhouse structure measured 24 feet 1/2 inch long and 7 feet 8 inches wide and had a canopy that measured 7 feet high at the sides and 7 feet 6 inches at the peak.[17] The sides of the deckhouse each had a waist-high bulkhead, above which were six slider windows having one fixed sash and one sliding sash. Each window sash measured 42 inches high and 24 inches wide.

The vessel had two doors, located at either end of the deckhouse. Passengers and crew embarked on and disembarked from the vessel at the bow (figure 2) by using a ladder attached to the forward area of the vessel. They entered or exited the deckhouse through its forward door, which slid to the side. The door at the aft end of the deckhouse swung outward. The aft door provided the crew with ready access to the outboard motor; however, the aft door could also be used for egress in an emergency. A passenger bench extended along each side of the vessel. The operator's console was forward of the bench seat on the starboard side of the vessel. The mate normally stood to the port of and slightly aft of the master. Vessel particulars are listed below.

Vessel type	Pontoon, small passenger
Maximum capacity	25 persons
Gross tons	2
Length	36 feet
Beam	8 feet
Pontoons (2)	2-foot-diameter circular cross-sectioned structures constructed of marine-grade aluminum
Propulsion type	Single, 4-stroke outboard, gasoline fuel, 90-horsepower Honda motor
Electrical power	12-volt d.c. engine-driven alternator and single battery
Fuel capacity	About 40 gallons (*Lady D* was constructed with one 20-gallon fuel tank; Seaport Taxi added a second fuel tank)
Steering system	Hydraulic
Throttle/clutch control	Independent, 2 cable
Communication system	1 VHF radio, Standard Horizon Eclipse+, model GX1250SA, fitted with a NOAA weather alert feature

[17] Estimated measurements of the deckhouse and its elements are based on a portion of the *Lady D*'s bulkhead that was recovered after the accident and on photographs of the *Misty Harbor II*, the fourth boat in the series and a pontoon vessel of comparable design.

Normal cruising speed for the *Lady D* was 6 to 7 knots; maximum speed was about 12 knots.

Safety Equipment

Based on regulatory requirements,[18] the *Lady D*'s COI indicated that the vessel was required to carry the following equipment for a load of 25 persons:

Lifejackets (adult)	25
Lifejackets (child)	3
Ring buoys (total)	1
With lights	1
With line attached	1

The COI indicated, "The minimum number of child-size life preservers required is three. If more than three children (or persons weighing 90 pounds or less) are carried, additional child-size life preservers shall be carried so that the vessel has an approved life preserver suitable for each child onboard."

According to the Seaport Taxi fleet captain, the *Lady D* carried 25 adult-size lifejackets and 10 to 11 child-size lifejackets. The adult-size lifejackets were stowed under benches along the starboard side and most of the port side. The child-size lifejackets were stowed forward under the portside bench. A placard showing how to don a lifejacket was posted on a bulkhead inside the deckhouse.

In addition to the lifejackets, the *Lady D* was equipped with a ring buoy that had a 50-foot-long attached throw-line and a strobe light on a 9-foot-long detachable line. The vessel also carried two equipment boxes: one for the master and the other for the mate. The master's box contained, in part, several items for minor emergencies, including two flashlights, a first aid kit, and an air horn.

Stability Certification

Evolution of Regulatory Stability Standards. The original stability rules for small passenger vessels in 46 CFR Subchapter T were based, in part, on Subchapter H, "Passenger Vessels," which contained the standards for passenger ships that were over 65 feet in length or carried more than 150 passengers. The regulations for evaluating the stability of large passenger vessels stipulated that a ship undergo an inclining experiment to determine the vertical and longitudinal location of the vessel's center of gravity and displacement in an unloaded condition and to verify its intact stability. This process involves deliberately heeling the vessel to varying angles and performing a series of calculations. The vessel owner typically has to hire a naval architect to conduct an inclining experiment.

[18] Federal regulations at 46 CFR 180 stipulate the lifesaving equipment and arrangements required for passenger vessels. Regarding the provision for lifejackets, the regulation states that an adult-size lifejacket must be provided for each person carried on board and that the number of child-size lifejackets must equal at least 10 percent of the persons permitted on board or such greater number as necessary to provide a lifejacket for each person who is smaller than the lower size limit of an adult-size lifejacket.

The promulgation of Subchapter T in 1957 resulted in a large number of existing small passenger vessels being required to meet the stability standards contained in 46 CFR Part 179. Recognizing that the design of most small passenger vessels was far simpler than that of large passenger vessels, the Coast Guard supplemented Subchapter T with a navigation and vessel inspection circular (NVIC) containing a simplified stability test (SST) that could be used in lieu of an inclining experiment to certificate the allowable passenger load for "T-boats," as vessels covered by Subchapter T are termed. The NVIC included passenger weight criteria for determining the allowable load used to calculate the vessel's stability. The assumed weight per passenger was 160 pounds, except that if the vessel was to operate on protected waters, the assumed weight per passenger was 140 pounds, based on a passenger mix of men, women, and children. (Further discussion of the SST protocol appears in the following section.) The 1957 version of Subchapter T also established limiting factors for determining the maximum number of passengers permitted on any vessel, including the length-of-rail criterion, the deck-area criterion, and the fixed-seating criterion.[19]

The Coast Guard's 1960 revision to Subchapter T included the SST for monohull vessels carrying more than 49 but not more than 150 persons. Subchapter T as revised did not contain stability standards for small passenger vessels carrying fewer than 50 passengers; however, if an OCMI questioned the stability of a vessel carrying more than 6 but fewer than 50 passengers, the Coast Guard could require that the vessel undergo a stability test. The stability rules gave an OCMI the discretionary authority to accept alternatives, equivalents, or departures from the standards when it could be shown that special circumstances warranted such actions, especially for existing vessels. In addition, departure from the stability requirements was permitted if, in the OCMI's judgment, the vessel was "of a type and structure which experience has demonstrated is safe for the proposed service."

At this time, pontoon vessels were categorized as passenger vessels of "unusual design" and if their stability was questioned, they typically were required to meet the stability standards in Subchapter H. Upon recognizing that more pontoon vessels were being used for commercial passenger service, in the late 1960s, Coast Guard headquarters revised Volume 4 ("Technical") of its *Marine Safety Manual* to provide the OCMIs with a pontoon (passenger vessel) simplified stability test (PSST). The policy in the manual outlined the recommended test protocol for pontoon-type small passenger vessels under 65 feet in length with operations restricted to protected waters. The PSST protocol, in general, followed that of the SST; however, because of the design differences between monohull and pontoon vessels, the formula and procedure for verifying the allowable load differed. (See following section on test protocols.)

The Coast Guard continued in its rulemaking efforts for small passenger vessels and on January 30, 1989, issued a notice of proposed rulemaking (NPRM) proposing that, except for those vessels that had to undergo an inclining experiment, all small passenger vessels carrying more than 6 passengers be required to pass a stability test. The NPRM

[19] The limiting factors are contained in 46 CFR 176.

proposed including in the regulations a PSST that was substantially the same as the version in the *Marine Safety Manual*. The NPRM addressed all pontoon vessels that were not more than 65 feet in length, did not carry more than 150 passengers, and operated only in protected waters. On September 24, 1990, the PSST test proposed for Subchapter T was revised to limit its applicability to vessels with two pontoons. This rule pertaining to pontoon vessel stability testing was included in the revision of Subchapter T that was finalized on January 10, 1996.

Testing Protocols. The purpose of a simplified stability test is to verify a vessel's intact stability for the carriage of passengers. The conduct of either an SST or a PSST is the responsibility of vessel owners or their representatives. A Coast Guard inspector is present to oversee and verify the validity of the test. Generally speaking, the protocols for both tests are similar, except as noted in the following discussion.

Pretest Actions. In advance of the actual test, a determination is made of the passenger allowance. The estimated number of passenger that a vessel can carry is calculated based on a review of the vessel's drawings or physical measurements using one of the following criteria:

- *Length-of-rail criterion*: One passenger for each 30 inches of rail at the sides and stern.
- *Deck-area criterion*: One passenger per 10 square feet of deck area, excluding spaces listed in 46 CFR 176.113, which include, among other areas, concession stands, toilets, lifesaving gear storage spaces, required aisle area, and fixed seating areas.
- *Fixed-seating criterion*: One passenger per 18-inch width of fixed seating.

Calculation of Heeling Moment(s). The SST protocol has always included calculations for wind heeling moment[20] and passenger heeling moment to determine whether a vessel, as built and proposed to be operated, has a minimum level of stability. Before the *Lady D* accident, the PSST protocol included a calculation only for passenger moment. The Coast Guard has since issued a policy letter changing the PSST to include a wind heeling moment calculation.[21]

In the test protocols, the passenger heeling moment is calculated based on the beam of the vessel and the number of passengers carried. A wind heeling moment is calculated based on the projected lateral surface of the vessel exposed to wind pressure.

Stability Proof Test. The heeling moment calculations are used to physically conduct a stability proof test on the vessel. The calculated moment that is greater (wind or

[20] In physics, a "moment" is the product of a quantity (such as a force) and the distance to a particular axis or point.

[21] "Other Information" discusses the postaccident actions taken by the Coast Guard as a result of the *Lady D* accident. One measure was the development of a job aid for conducting a stability test, which appears in appendix B of this report.

passenger) is applied to the vessel, and the vessel's loss of freeboard[22] is measured. The physical proof test simulates a full load using the number of passengers allowed by the vessel design and the required crew multiplied by the weight standard (140 pounds per person on protected waters). The SST standard allows for only one-half of the freeboard (or 14° of heel, whichever is less) to be submerged during the proof test. If the vessel's loss of freeboard from heel is greater than stipulated in the standard, it fails the test.

The PSST in effect before 2005 used only a calculation for passenger heel in the proof test. The physical proof test involves moving a simulated full load test weight based on the estimated number of occupants multiplied by the weight standard (140 pounds per person on protected waters). The test weight is first centered on the vessel and then moved to the extreme outboard transverse and longitudinal edges of the vessel. The vessel must pass a deck edge immersion test for longitudinal weight movements and a reserve buoyancy test for transverse weight movements. If the deck edge of the pontoon vessel submerges during the longitudinal immersion test or the vessel loses more than 50 percent reserve buoyancy during the transverse reserve buoyancy test, the pontoon vessel fails the test.

If a vessel fails the physical proof test in the SST or PSST protocol, the owner must then elect to make one or more of the following changes to reduce the heeling moment so that the vessel can pass the proof test: carry fewer passengers, ballast the vessel, or reduce the vessel's wind profile area, if applicable. The SST and PSST calculations and proof tests ultimately determine the number of occupants permitted on a vessel, unless it has physical characteristics (fixed seating, rail length, or deck area) that further limit passenger capacity. Table 2 compares the two tests.

Table 2. Comparison of simplified stability test and pontoon simplified stability test

Test Component	SST	PSST
Condition of vessel	Specified in job aid	Specified in new PSST job aid
Test weight	Equivalent to total passenger load	Same
Wind heel moment calculations	Based on lateral area affected by wind	Before *Lady D* accident: none After *Lady D* accident: (a) 300 x length (b) same as SST if wind heel > passenger heel
Passenger heel moment	Function of beam ÷ 6	Function of beam ÷ 2*
Pass/fail		
Transverse	14° of heel or ½ freeboard, whichever is less	Loss of reserve buoyancy** cannot be more than 50%
Longitudinal	None	Deck edge cannot submerge

* Passenger heel for PSST is 3 times the requirement for the SST. Total test weight must be moved from centerline to deck edge at side of vessel.

**In the case of the PSST, reserve buoyancy is the nonsubmerged internal volume of the pontoon over which the test weight is moved.

22 Freeboard is the distance from the vessel's deck to the surface of the water.

***Lady D* Certification.** As noted earlier, the *Lady D* was the third in a series of vessels built for Baltimore Harbor Shuttle. On August 12, 1992, the first vessel in the series, the *Fells Point Princess*, was subjected to a stability proof test to establish the maximum number of persons that could be carried on board.

According to Coast Guard officials, field notes indicate that the test was not conducted in accordance with the PSST protocol contained in the *Marine Safety Manual*, but rather in accordance with CG-4006, a simplified stability test form, or job aid, that was applicable to monohull vessels. In the SST for monohull vessels, both a wind heeling moment and a passenger heeling moment are calculated. The larger of the two moments is then applied to the vessel by shifting weights a distance necessary to achieve that moment. A review of the test form shows that during the stability proof test of the *Fells Point Princess*, the passenger heeling moment was not properly calculated, and, as a result, the calculated wind heeling moment exceeded the passenger heeling moment. The calculated wind heeling moment was then applied to the vessel during the test.[23]

Based on the results of the 1992 stability proof test, the Coast Guard issued a stability letter and COI allowing 25 persons to be carried aboard the *Fells Point Princess*. Over the next 4 years, Susquehanna Santee Boatworks constructed the *Raven*, the *Lady D,* and the *Misty Harbor II.* Although the four vessels were the same general size and had the same configuration, their deckhouse enclosures differed. The first two vessels (the *Fells Point Princess* and the *Raven*) had open sides in the deckhouse and no windows. The next two vessels (the *Lady D* and the *Misty Harbor II*) were fitted with glass windows.[24] Despite the design differences, none of the three subsequent vessels was subjected to a stability proof test. Rather, they were granted sister vessel status,[25] and each was allowed to carry the same maximum number of persons (25) as the *Fells Point Princess*.

Before the capsizing, the *Lady D* had last received a COI, good for 5 years, from the Coast Guard on February 28, 2002. The COI specified that the vessel carry no more than 25 persons "not more than 1,000 feet from shore under reasonable operating conditions." Following the accident, the Coast Guard conducted tests of the sister vessel *Patricia P* (formerly the *Fells Point Princess*) and identified that the maximum passenger load permitted by the *Lady D*'s COI was in error. Additional information about the Coast Guard postaccident actions appears later in this report, under "Other Information."

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[23] Review of the test form after the *Lady D* accident showed that if the passenger heeling moment had been being properly calculated, it would have exceeded the calculated wind heeling moment, which means that it should have been applied during the test.

[24] In a postaccident study contracted by the Safety Board, the weight of the *Lady D*'s windows and doors was estimated to be in excess of 400 pounds. See "Tests and Research."

[25] The Coast Guard *Marine Safety Manual* provided guidance on when a vessel could be deemed to be a sister vessel. In chapter 6 D, the manual states "The following general guidelines have been developed to provide guidance and to help keep the determination of 'sister vessel' as uniform as possible: the previously inclined vessel and the proposed sister vessel should have been built within approximately 2 years from one another; the vessels must be built by the same shipyard; and the same basic drawings should have been used in the construction of both vessels." Additional Coast Guard guidance on waiving of stability tests based on sister vessel status was provided by NVIC No. 14-81 and stability regulations for inspected vessels at 46 CFR 170.175.

Wreckage

During rescue efforts, the crew of the responding Navy vessel lifted one side of the *Lady D* by positioning the bow gate of the LCB-8 under one of the *Lady D*'s pontoons. As a result, investigators could not readily distinguish what damage to the vessel might have been caused before or during the capsizing and what might have been caused by the recovery efforts.

When the *Lady D* was righted on March 7, the day after the accident, investigators found that the wreckage comprised only the deck, pontoons, engine, fuel tanks, operator's console, and boarding ladder (figure 3). Part of the bulkhead from the aft end of the deckhouse was partially attached to the aft deck. To right the vessel, divers cut this partial piece loose. The rest of the deckhouse was missing and never recovered.

Figure 3. *Lady D* after being righted the day after the accident. Attached to the deck are airbags that were used to help right the vessel. Most of the deckhouse was missing and never recovered.

The port passenger bench was still attached to the deck of the wreckage. The starboard passenger bench was missing and was never recovered. The canopy section of the deckhouse was discovered during sonar searches of the harbor but was not recovered.

During a wreckage survey performed on March 9, investigators found the master's chair nearly detached from its mounting base and tilted to the starboard side. The starboard pontoon had damage on its aft outboard side (a dent and a hole). The steering system was found to operate satisfactorily, but the cover from the throttle/clutch control mechanism was missing. Investigators did not test the vessel's engine or VHF radio because they had been submerged about 24 hours.

Two months after the accident, on May 11, 2004, the Safety Board contracted with an engineering consulting firm, John J. McMullen Associates, Inc. (JJMA),[26] to perform an additional survey of the *Lady D* wreckage. The contractor began by suspending the *Lady D* in a travel lift, visually examining the vessel, and measuring the various components. Damage to the starboard pontoon was observed, with water leaking from the damaged area. The Seaport Taxi director stated that the damage had occurred during rescue operations after the capsizing. Both pontoons were checked, but only the aftmost section of the starboard pontoon showed evidence of water.

To drain all the water out of the pontoon, a small hole was drilled in the hull. (The vessel was hanging in the travel lift with the stern lower than the bow.) The hole was then plugged with a screw and gasket, and the damaged areas were sealed with epoxy. When the epoxy had set, the boat was launched and freeboard readings were taken at the bow, amidships, and stern of the vessel and at the aft ends of both pontoons.

Waterway Information

The Baltimore Harbor areas, located at the head of the Patapsco River, are accessed through a series of channels. The accident occurred in the Northwest Harbor near a floating aid to navigation ("NH") marking the entrance to the West Channel from the East Channel. The West Channel extends 0.8 mile in a northwesterly direction to a turning basin near the Inner Harbor, Baltimore's central tourist location and the terminus of the Patapsco River. In the Northwest Harbor area, the operating depth for vessels is 21 to 25 feet.[27] According to NOAA chart 12281, the East Channel turning basin, located close to the accident site, has a depth of 49 feet at mean lower low water. The area just northeast of the navigation aid marking the entrance to the West Channel has a water depth decreasing to 15 feet along the west side of the turning basin.

The mean range of tide is 1.1 feet at Baltimore. Prolonged winds of constant direction may cause substantial variation in the tide. Currents in the harbor are 0.8 knot on the flood and ebb. The verified water level at 1600 for Fort McHenry was 1.12 feet above

[26] On April 1, 2005, JJMA was acquired by Alion Science and Technology, another engineering firm that provides support services to the government and the commercial maritime industry. The Safety Board subsequently tasked Alion Science and Technology, JJMA Maritime Sector, to evaluate the intact static and dynamic stability of the *Lady D*, which is discussed later in "Tests and Research."

[27] National Oceanic and Atmospheric Administration, National Ocean Service, *United States Coast Pilot*, Vol. 3 (Atlantic Coast: Sandy Hook, NJ, to Cape Henry, VA), 38th ed., 2005, p. 358.

mean lower low water.[28] Currents near Fort McHenry and the Northwest Harbor entrance are described as weak and variable.[29]

Management Information

Parent Organization.

At the time of the accident, Seaport Taxi operated under the auspices of the Living Classrooms Foundation (Living Classrooms), a nonprofit organization whose mission is to provide experienced-based training, with emphasis on serving at-risk youth. In 1999, Living Classrooms created the National Historic Seaport of Baltimore (NHS) to oversee the foundation's maritime assets and to partner with the owners of other maritime attractions in and around Baltimore's Inner Harbor. (See table 3.) According to a spokesman, the following year, the NHS purchased Baltimore Harbor Shuttle, an existing water taxi company servicing the area, as a way to link all the partnership sites. The NHS then renamed the shuttle service Seaport Taxi.

Table 3. Organization of National Historic Seaport of Baltimore

NHS Assets	NHS Affiliates
Baltimore Marine Museum and its historical vessels and structures as follows: U.S. Coast Guard Cutter *Taney,* Lightship LV#116 *Chesapeake,* U.S. Submarine *Torsk,* Seven Foot Knoll Lighthouse	Baltimore Museum of Industry
	Top of the World
	Fort McHenry National Monument and Historic Shrine (National Park Service)*
U.S.S. *Constellation* Museum	Star-Spangled Banner Flag House
Seaport Taxi	Civil War Museum (Maryland Historical Society)
	Sail Baltimore/Visiting Ships Program
*NHS manages the Patriots of Fort McHenry, a community group that helps with educational activities and funds miscellaneous activities such as fireworks displays not paid for by the Federal government.	

Following the accident, Living Classrooms ceased its Seaport Taxi operation and entered into a partnership agreement with Ed Kane's Watertaxi Service to provide shuttle service.

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28 NOAA-National Ocean Service Center for Operational Oceanographic Products and Services, "Tides Online" <http://tidesonline.nos.noaa.gov>, "Historical Data Retrieval," verified 6-minute water level data for Baltimore, Fort McHenry, Patapsco River, Maryland, collected on March 6, 2004.

29 NOAA-National Ocean Service Center for Operational Oceanographic Products and Services, tidal current secondary station prediction adjustments for Patapsco River: Fort McHenry, NW Harbor entrance <http://140.90.121.76/currents05/tab2ac5.html>.

Management Hierarchy

Living Classrooms officials were not involved in the day-to-day operations of the water taxi service. The officers who established the vessel operating policies and procedures for Seaport Taxi were the NHS director, the Seaport Taxi director, and the fleet captain.

Director, National Historic Seaport of Baltimore. The NHS director oversaw planning for seven entities: Seaport Taxi, Baltimore Maritime, the U.S.S. *Constellation*, Paddle Boats, Patriots of Fort McHenry, the Baltimore Waterfront Promenade, and National Historic Seaport Administration.

Director, Seaport Taxi. The Seaport Taxi director told Safety Board investigators that, because of his interest in boats and motors, he had taken Peterbilt Motors Company and General Motors Corporation training classes that dealt with vessel mechanics. In 1986, he qualified for his first Coast Guard master's license, which authorized him to operate passenger vessels up to 25 tons. While fully employed with R. J. Reynolds, he worked part time operating six-passenger charter boats in the Long Island, New York, area, and then water shuttle vessels for Baltimore Harbor Shuttle, primarily during the summer. By this time, his license had been upgraded to 100-ton vessels, master of inland and coastal waterways. He said that, in 1993 and 1994, he bought two vessels and worked as an owner/operator for Baltimore Harbor Shuttle until mid-1995. He then sold the vessels and served occasionally as a captain for the water shuttle service.

In 2001, after Living Classrooms bought and renamed the water shuttle service Seaport Taxi, he was hired as the Seaport Taxi fleet captain. After 2 months, he was promoted to Director, Seaport Taxi, the position he held at the time of the accident. As director, he said that he oversaw the taxi operation "pretty much in its entirety from fiscal issues, marketing issues, operations and maintenance, delegating maintenance as required, scheduling, reviewing who's hired, and overseeing performance." He oversaw 2 permanent employees (the fleet captain and the office manager) and the vessel crews, which numbered 5 or 6 full-time and 5 or 6 part-time employees during the off-season (such as the master of the *Lady D*, who worked on weekends) and more than 60 employees during peak season. During normal daily operations, he sometimes served as master of one of the boats in operation and provided guidance and information to other vessels in the fleet.

Fleet Captain, Seaport Taxi. The fleet captain told Safety Board investigators that he was involved in social work for about 20 years before entering the marine industry. After purchasing a 40-foot sailing yacht, he outfitted it as a charter boat and obtained his first Coast Guard license. Before he was hired as one of Seaport Taxi's first captains in 2001, he operated his own vessel and charter vessels of various designs (sailboats, yachts, riverboats, gambling boats, and so forth) for a number of companies.

As a Seaport Taxi captain, he operated all the boats in the fleet, including the *Lady D*. He stated that in the first year after Living Classrooms purchased the water taxi company, "there was a considerable amount of repair and restoration work necessary on the boats. So, consequently, you either ran everything or you didn't do much…."

Within months of being hired as a vessel captain, he was promoted to fleet captain. As such, he was responsible for supervision management, boat maintenance, and scheduling boat repairs. His immediate supervisor was the Director of Seaport Taxi. Like the director, the fleet captain sometimes operated one of the boats in service. If the director was not on board a vessel, the fleet captain, as senior company official on the water, provided guidance and information to other vessels in the fleet.

Other Seaport Taxi Employees

Three other Seaport Taxi employees with oversight of certain company operations interacted with the *Lady D*'s master on the day of the accident.

Office Manager. The Seaport Taxi office manager was responsible for day-to-day administrative work, including advising the crews as to which vessels would be operating and who would be assigned to each boat, preparing the cash boxes for the mates, and issuing tickets. She also monitored channel 71 on the VHF radio in the office at all times, fielding requests for action from the vessel operators, and listened for weather updates that she passed on to the fleet via a hand-held walkie-talkie UHF (ultrahigh frequency) radio.

Senior Captain on the Water. If the Seaport Taxi director and the fleet captain were not operating a vessel, typically the master with the most seniority would serve as senior captain on the water, relaying advice and information to other vessels. The master serving as senior captain on the water on the day of the accident had worked a total of 9 years for Baltimore Harbor Shuttle and Seaport Taxi.

Fort Coordinator. Seaport Taxi's fort coordinator was a part-time employee who worked weekends managing the embarkation and debarkation of visitors at Fort McHenry. His duties included escorting and counting the passengers as they boarded a vessel, conferring with the mate who was responsible for recounting the passengers as they took their seats, and verifying with the master that he too had done a final count of the people on board. The fort coordinator also maintained a log of the people who had visited the fort.

Operational Information

Docking Agreements with City

The City owned the dock at Fort McHenry where Seaport Taxi landed and leased it to NHS. As part of the lease agreement, the company had to maintain the dock. However, when the Fort McHenry pier was damaged by a hurricane, NHS obtained permission from the fire chief to land at the fireboat base (the command center). The company had an access agreement with Fort McHenry that permitted the water taxi passengers to enter the fort's gate.

Daily Operations

In 2003, Seaport Taxi transported 200,000 paying customers. As noted earlier, the taxis operated on two routes—an inner loop between Harbor Place and Fells Point and an outer loop between Fells Point and Fort McHenry (refer to figure 1). Trips usually started at Harbor Place. The trip from Harbor Place to Fells Point was nonstop and took 12 to 15 minutes. On arriving at Fells Point, the water taxis disembarked passengers interested in the attractions at that stop or in the sites on the outer loop. Taxis operating on the inner, or "local," loop then returned to the Inner Harbor marina with passengers interested in the inner loop stops.

The Seaport Taxi director stated that how often a boat made a loop depended on the passenger traffic and the number of requested stops. He indicated that the COIs of all vessels in the fleet permitted them to go as far as Fort McHenry and Canton.

Passenger Accountability

According to the Seaport Taxi director, because of the "caravan" nature of the water taxi business, with passengers boarding and disembarking a vessel every 7 to 15 minutes, the company "had yet to come up with a workable system for constantly monitoring how many people [were] on a specific boat" at any given time. Every time a taxi left a particular docking point, the operator would issue a fleet-wide broadcast advising how many people were on board; however, this company practice was meant to provide the working fleet and the office manager with some idea of where the respective boats were operating, when they might be expected to dock, and where the greatest customer demand was. The only docking site where Seaport Taxi documented an exact passenger count was at Fort McHenry, which was a requirement of their partnership agreement. Seaport Taxi assigned one employee—the fort coordinator—to the site to control the movement of vessel passengers to and from the fort, to prevent unauthorized people from entering the fort, and to prevent visitors from becoming stranded at the fort. He was required to maintain a log documenting each voyage and the number of passengers on the boat, which was turned in to the office each evening and which was later used to prepare a monthly report to Fort McHenry officials.

On the day of the accident, witnesses alerted the BCFD emergency control center that the capsized vessel had originated at Fort McHenry. BCPD patrol officers in the area stopped at the fort, obtained a count of how many people were on board the *Lady D* from Seaport Taxi's fort coordinator, and relayed the information to the responders.

Following this accident, after discussions with investigators, Seaport Taxi placed a box at each taxi depot in which the vessel crewmembers were required to deposit a manifest log indicating how many passengers were onboard before their vessel departed the dock.

Weather Policies and Procedures

According to the Seaport Taxi director, the company's standing instruction for operating in inclement weather was that if masters encountered an electrical storm, restricted visibility, fog, or another condition that in their experience would dictate finding a safe harbor, they should do so. In classroom and on-the-job training, potential new hires were instructed not to wait until they were told to get off the water. The director said that he considered it part of "good seamanship and common sense" not to operate in conditions in which a Coast Guard-licensed master was not comfortable. He also told investigators that he did "not want to hamper independent decisions out there because what's happening in the Inner Harbor may be totally different than what's happening out at Fort McHenry, or conversely." He indicated that he respected the decisions of licensed mariners, stating, "It's their judgment. It's their license and I would expect that courtesy when I'm running a boat, and that's the same courtesy I give them."

The director further said that he advised applicants that windage[30] on pontoon vessels was significantly greater than on a conventional monohull vessel. He added that the masters "learn[ed] quickly" that they would not be able to land a vessel if they did not understand the effects of wind on the pontoon boats' high profile. The company's fleet director added that Seaport Taxi had three criteria in its stated weather policy requiring masters to put their vessels "into the bulkhead" and "tie up": when visibility was "dramatically reduced"; when lightning was in the immediate area; or when the wind was over 30 to 35 knots, depending on the operating route.

The master of the *Lady D* had operated that vessel for most of the time he had been employed by Seaport Taxi, repeatedly traversing the Northwest Harbor area. He stated, "The water is a little rougher as you go out the [Patapsco] river than when you are staying in the Inner Harbor…area." He said that he had made it a personal practice to check the Weather Channel before going to work so that he might be prepared for the conditions that day. He said that on March 6, the forecast for the "4 o'clock time frame" did not indicate that "this humongous wind" would be coming into the harbor area.

The master stated that he understood the company guidance permitted operating in winds that were "35 knots or under" and "that is what I generally go with." He further stated, "If it gets 40 knots or above, that is always a no-go for…going out to Fort McHenry." He indicated that he thought he had been caught out on the water when the winds had been 50 knots. He said, "The boat was leaning," but that he had been able to put the vessel into the wind and was "okay."

Seaport Taxi officials told investigators that in past years, "if the windage was such that it was deemed…inappropriate to have [the *Lady D*] out there [operating on loop 2], they would assign a heavier boat with larger engines to the route. The senior captain on the water indicated that earlier in 2004, the *Lady D*'s master had radioed "that he felt uncomfortable" in the wind conditions, and had asked that a heavier boat take over the route, which company officials arranged to do.

Following this accident, Seaport Taxi revised its weather operating policy to place specific wind and sea state restrictions on vessels as shown in table 4. Company officials indicated that they met with their vessel operators to stress safe procedures for operating in inclement weather, including when they must suspend operations. The company also

[30] The surface of a vessel that is exposed to the wind.

equipped each vessel in its fleet with an emergency alert NOAA weather radio to facilitate the crew's receiving accurate and timely information.

Table 4. Seaport Taxi's postaccident operating restrictions for wind and wave conditions

Boat	Sustained Winds (mph)	Wind Gusts (mph)*	Sea State (feet)
Raven[a]	30	35	2
Phoenix	30	35	2
Migeni	30	35	2
Patrick Duffy	25	30	2
Eagle	25	30	2
*Wind gusts lasting 15 seconds or longer.			

[a] This vessel is not the *Raven* that was constructed in series to the *Lady D*.

Maintenance

Lady D History. According to the Seaport Taxi director, when he joined the water taxi company, it had received several CG-835 forms, *Notices of Merchant Marine Inspection Requirements*, from the Coast Guard for deficiencies[31] on the *Lady D* such as a cracked hold or cracked steps. He indicated that Seaport Taxi had improved the *Lady D*'s record, and that Coast Guard inspectors had not noted any structural deficiencies during the vessel's last annual examination on February 27, 2003.

The Seaport Taxi director and the fleet captain both indicated that they were last aboard the *Lady D* on March 2, 2004. The fleet captain said that he had operated the *Lady D* less than a week before the accident and noted no problems. The director indicated that the last time he operated the *Lady D* was on February 25, when he took it to attend a meeting at the *Constellation*. He said, "As far as the operational systems, [the vessel] seemed fine. Radio was working."

The Seaport Taxi director said that in summer 2003, there had been a "little problem" with the *Lady D*'s steering system, but greasing the points solved the problem. Since then, he had not received any reports about steering problems until 3 or 4 weeks before the accident, when one captain submitted a log report complaining about "a little glitch in the steering." The director found an accumulation of salt and corrected the problem.

Officials indicated that the *Lady D* was the only vessel in the fleet with a four-stroke Honda engine and "the engine mount on the vessel constantly develops cracks that need to be attended to." The company director stated that shortly before Hurricane Isabel, in September 2003, Seaport Taxi had the engine replaced with a new Honda engine that was "reinforced better than it was from the factory." He indicated that as far as structural work was concerned, the front deck had been reconstructed, reinforced, and strengthened and that the pontoons had been welded and repaired.

Seaport Taxi provided investigators with 11 bills submitted from contractors to Living Classrooms for various repairs made to the *Lady D* between November 8, 2000, and October 4, 2003. According to the bills, repairs to the pontoons were made in 2001 and 2002.

[31] A "deficiency" is any failure to meet minimum requirements of vessel inspection laws.

Maintenance Program. According to the NHS director, about 10 percent of the Seaport Taxi annual operating budget, or $50,000 to $60,000, was spent on maintaining the fleet. The Seaport Taxi director said that he did not keep records of routine maintenance performed by company personnel. However, bills from contractors for repairs and examinations that necessitated removing a vessel from the water had to be submitted on a purchase order to Living Classrooms for payment, meaning that the accounting department of Seaport Taxi's parent company maintained documentation on extensive maintenance.

The Seaport Taxi director stated that the company did not require personnel to do prescheduled daily, weekly, monthly, or annual checks and upkeep of the fleet's vessels and their components. He said that the pontoon vessels themselves were "very simple"; the operating equipment included a self-lubricating hydraulic steering system and either a two-cylinder or a four-cylinder engine. Most routine maintenance, therefore, was limited to checking for leaks, replacing seals, adding oil, greasing engine parts, and changing spark plugs, tasks that were affected, in large part, by the number of hours a vessel was in use.

The director indicated that Seaport Taxi had developed what he termed a "proactive" vessel maintenance program for the company's fleet. He said the captains were required to check all systems, lights, horns, and steering each time they were assigned to a vessel and to make sure everything was operating properly and to their satisfaction before they put the boat in service. In addition, the masters were required to maintain a captain's shift log on which they provided line-item information such as the time of day they began operating a particular vessel, how long they were on duty, and how much gas or engine oil they added during their shift, as well as any problems or limiting conditions they encountered. At the end of every shift, the logs went to the Seaport Taxi office for review by the office manager and fleet captain. Seaport Taxi provided the Safety Board with 153 shift logs representing 130 days of operation between May 2003 and February 2004. On November 19, 2003, the master who operated the *Lady D* that day noted that conditions were "windy"; however, his log does not indicate that he tied up as a result of the weather conditions.

Meteorological Information

Many Federal, State, and private entities have installed automated weather observation sites independently of one another. The format of data and frequency of collection vary. The Safety Board obtained and reviewed recorded meteorological information from a variety of sources, including the NWS and privately held mesonet[32] systems throughout the area. A summary of the operations of several weather sources and the report data captured by their equipment follows.

[32] Mesonet is a regional network of observing stations (usually surface stations) designed to diagnose the features in a mesoscale weather system, that is, a system whose dimensions generally range from several miles to several hundred miles.

National Weather Service

Forecasters at the NWS weather forecast offices use a variety of observational data to diagnose and assess current meteorological conditions and the state of the atmosphere. They merge this assessment with output from computer models run at the National Centers for Environmental Prediction (NCEP), and they collaborate on forecast decisions with forecasters at neighboring weather forecast offices and the NCEP Storm Prediction Center. According to agency officials, the NWS routinely broadcasts advisories, warnings, and other meteorological data to mariners throughout the Chesapeake Bay area via NOAA Weather Radio (NWR) All Hazards. NWR coverage is complete over the entire Washington-Baltimore-Chesapeake Bay area, and, according to agency officials, the NWR was fully operational on the day of the accident.

Standard observational data that are integrated and displayed on the forecasters' workstations include basic surface observations from Automated Surface Observing System (ASOS) and similar Automated Weather Observing System (AWOS) sites[33] at airports; data from weather surveillance radar 88 Doppler (WSR-88D) systems[34]; basic parameters measured through the upper atmosphere by balloon soundings; temperature and wind recorded by aircraft; and satellite imagery.

The weather forecast office having primary responsibility for monitoring the area that includes Baltimore Harbor is the Baltimore-Washington site near Sterling, Virginia. On the afternoon of March 5, 2004, the Baltimore-Washington forecast office had issued a small craft advisory for all of Chesapeake Bay, including the Inner Harbor at Baltimore. The small craft advisory remained in effect throughout the following day.

On March 6, a radar operator and a lead forecaster arrived at 1350 and 1500 respectively for their evening shift at the Baltimore-Washington forecast office. They said that they received briefings from the day-shift meteorologists they relieved, who both advised them that a cold front between the Appalachian Mountains and the Atlantic Coast had generated showers and thunderstorms; however, as was typically the case for that time of year, the storm conditions were expected to diminish in intensity and coverage as they moved east due to dry air aloft and to westerly blowing winds.[35]

The night shift meteorologists said that they reviewed the available data and agreed with this assessment.

The NWS nightshift personnel indicated they followed their usual routines. The radar operator primarily was responsible for monitoring the WSR-88D. The lead forecaster was responsible for maintaining a continuous weather watch by reviewing

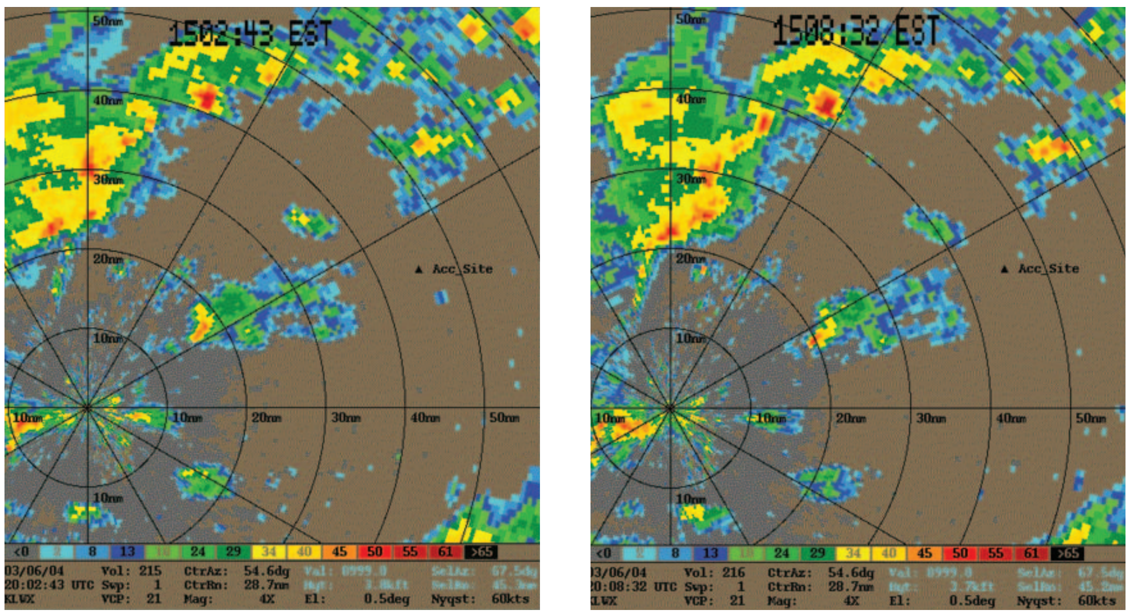
[33] The ASOS program is a joint program between the Departments of Commerce, Transportation, and Defense. AWOS is primarily a Department of Transportation program.

[34] The WSR-88D is a short-range weather radar system.

[35] A postaccident review of the storm environment analyses performed by the day-shift meteorologists at Sterling revealed that they did not include anticipated environmental changes in their analysis of soundings, which resulted in the observation that the chances for convective instability were small for the rest of the day.

model data, forecast soundings, observations, and radar and for issuing products and forecasts (aviation and marine), as needed.

The WSR-88D radar sites nearest Baltimore Harbor monitored by the radar operator at the Baltimore-Washington weather forecast office included the installation at his own office (Sterling, or LWX), the Dover Air Force Base site, and the central Pennsylvania site just northwest of State College. These radars are 52, 70, and 135 miles, respectively, from the accident site. In addition, the radar operator could access data from neighboring sites at his own workstation and monitor multiple sites concurrently and through mosaic images. Figure 4 shows selected LWX WSR-88D images displayed shortly after 1500.



About 50 minutes before the Lady D boards passengers at Fort McHenry. Intense weather echoes (storms) are seen about 40 miles north-northeast of the accident site.

Six minutes later, the storms have moved about 5 miles to the east.

Figure 4. WSR-88D, or Doppler weather radar, shows detailed images of precipitation (snow, rain, hail) and other phenomena, including air motions within a storm. The images above show weather radar echoes, some of which are intense to extreme, moving to the east. The colors noted on the bottom of the images relate to weather radar echo intensities (in decibels of Z [dBZ], where Z = energy reflected back to radar). The colors blue to yellow indicate intensity ranges from weak, moderate, to strong, and the colors orange to red indicate ranges from very strong, intense, to extreme.

According to the radar operator at the Baltimore-Washington weather forecast office, he was receiving few aircraft soundings to the west of the cold front, which might have alerted him to increasingly unstable conditions. In addition, he did not recall his office's weather processing system generating a "meaningful" radar alarm that might have alerted him to a significant change. He later advised NWS officials who conducted an independent investigation that he had expected the storm to dissipate as area spring storms had typically done in the past.

In the meantime, the lead forecaster said that he was routinely monitoring various systems. Data transmitted to the forecasters' workstations included wind gust data captured at various weather observation sites. Table 5 shows the wind gusts recorded by weather observation systems west of Baltimore Harbor on March 6.

Table 5. Recorded winds gusts within about 85 miles of accident site

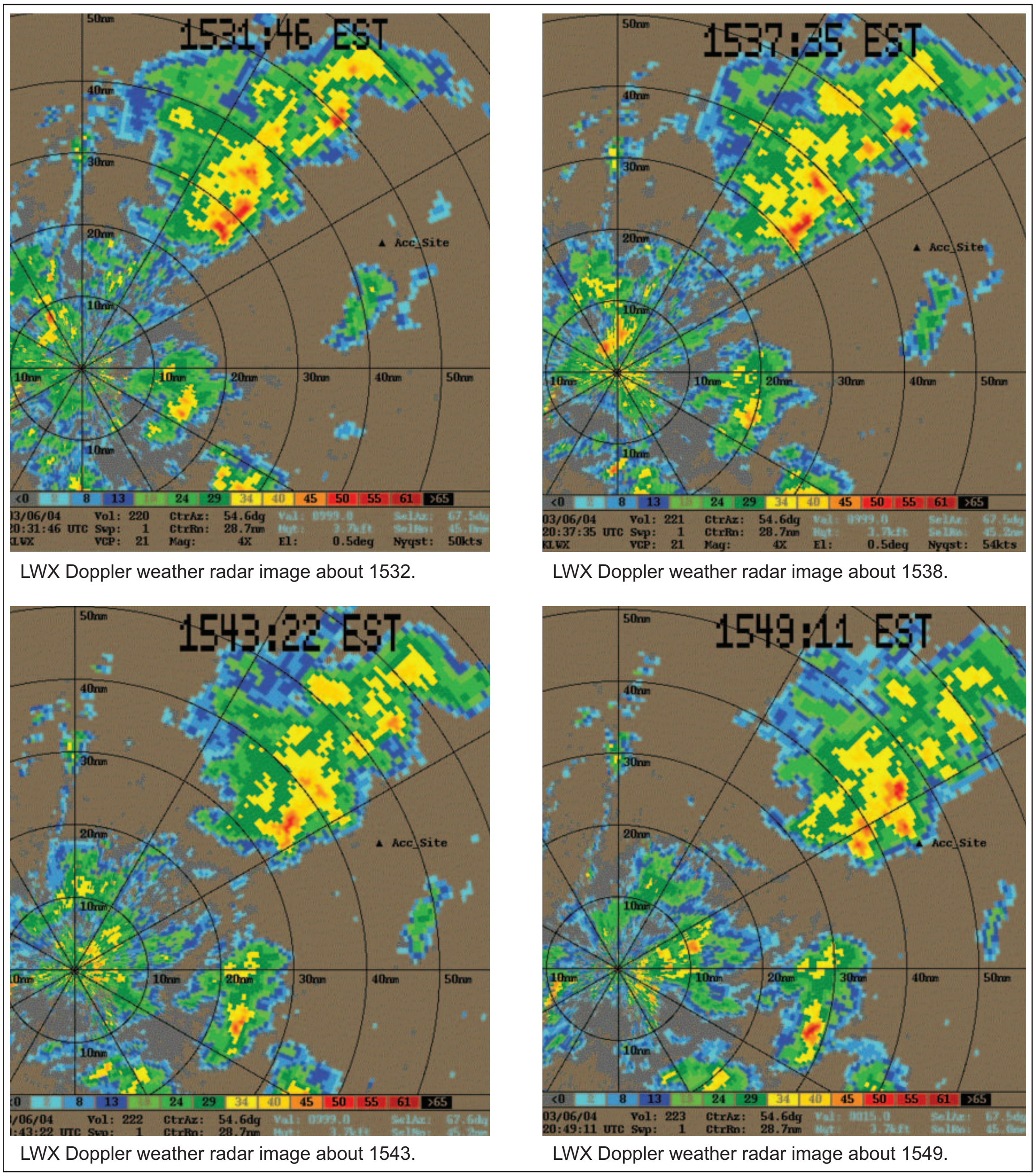
Time	Wind Direction (degrees true)	Station	Wind Gusts (knots)
1440	270	Martinsburg	36.9
1453	290	Martinsburg	35.9
1520	300	Frederick	32.1
1520	300	Culpepper	33.0
1544	310	Reagan National	46.0

The lead forecaster said that based on "isolated thunderstorm activity" and "after noticing some gusts in observations around 30 knots," he began work on issuing a short-term forecast for isolated thunderstorms with wind gusts to 35 mph. As the lead forecaster was working on verifying the conditions for the short-term forecast, he observed a storm cell passing over nearby Reagan Washington National Airport, producing a wind gust measuring 46 knots at 1544. He said he immediately alerted the radar operator about his observation and disseminated the short-term forecast at 1549. The Doppler radar images in figure 5 show the progress of the intense weather radar echoes between 1531:46 and the time the short-term forecast was issued.

The radar operator said that he immediately interrogated the cell using the WSR-88D at his location. The forecasters at the Baltimore-Washington weather forecast office also had access to radar data from other agencies' observing systems but not through their NWS workstations. At the time of this accident, for example, the forecasters could obtain radar data from the terminal Doppler weather radars (TDWRs) that the Federal Aviation Administration has installed at various airports. To do so, however, the radar operator had to switch to a personal computer to access and review the TDWR data.[36]

In this case, the radar operator accessed the TDWR at Baltimore-Washington International Airport to verify that the observation was legitimate and to determine where and when the storm posed a threat. He said that interrogating the storm and preparing the special marine warning to include Baltimore and a larger portion of Chesapeake Bay took about 8 minutes. The special marine warning was issued to area vessel operators at 1605, about 7 minutes after the *Lady D* had capsized.

[36] The NWS has since initiated a project to integrate TDWR data into its workstation systems. Information about additional measures the NWS has taken as a result of the *Lady D* accident appears in the following section.



LWX Doppler weather radar image about 1532.

LWX Doppler weather radar image about 1538.

LWX Doppler weather radar image about 1543.

LWX Doppler weather radar image about 1549.

Figure 5. LWX Doppler weather radar images showing the movement of storms from west to east toward the Baltimore Inner Harbor during the period 1532 to 1549. When the Seaport Taxi office manager radioed the fleet at 1558 that the worst parts of the storms were going to miss their area, she described conditions similar to those shown at 1549:11.

National Weather Service Postaccident Assessment

Following the *Lady D* capsizing, the NWS conducted its own service assessment of events and conditions preceding the accident to address questions related to its operations: In particular, did the NWS have sufficient capabilities to provide adequate warnings to mariners within the Baltimore Harbor and the greater Chesapeake Bay areas, and what meteorological data collected by private and public agencies in the Baltimore area could be readily collected and used by the NWS?

The NWS assessment team determined that the performance by the forecasters on duty was adversely affected by their preconceptions about the environmental conditions, which ultimately forced the meteorologists to operate in a reactive mode. The team further found that a more aggressive and more efficient approach by forecasters in analyzing the evolving weather conditions could have increased their concern about the potential for high winds. This, in turn, could have resulted in timelier and more complete information being provided in forecast and warning services.

The assessment team also found that the forecasters did not make optimum use of available equipment. Equally important, the mesonet and TDWR system data that could have alerted the forecasters sooner to deteriorating conditions were either not available at all or not available in a format that they could use. As a result, the Sterling forecasters updated products to reflect thunderstorms and higher wind speeds only after thunderstorms intensified and higher-than-expected winds became apparent in surface observations.

In June 2005, the NWS issued its final report, which discusses the findings of the service assessment and identifies recommended actions for improved performance. (See table 6.) According to an NWS official, the agency's assessment report was made available to weather forecast offices (WFOs) nationwide by means of the NWS website. The training exercises developed by and for the Sterling weather forecast office will be disseminated throughout the eastern region and then to other regions. In addition, the Sterling weather forecast office may create a weather event simulator scenario or distance training session that will be made available to interested offices. The NWS spokesperson indicated that the training developed is optional for WFOs; however, agency officials anticipate that weather field offices with marine forecast responsibilities will very likely access and use the training.

Digiwx System Sensors

Belfort Instrument Company, a Baltimore-based manufacturer of environmental measurement systems, provided data logged from two of its Digiwx (digital weather) System sensors located near the accident area. One Digiwx sensor is installed at a field elevation of 10 feet on the end of the dock at the Baltimore Marine Center, about 0.54 nautical mile (nm) north of the accident site. The second system sensor is installed at a field elevation of 181 feet on the University of Maryland's Shock Trauma Center in downtown Baltimore, about 2.7 nm west-northwest of the site. The captured data from the Baltimore Marine Center sensor indicate that about 1555, the wind speeds were 12 knots with gusts to 18 knots. Between 1555 and about 1559, the winds increased to 21 knots with gusts to 37 knots (1558:58 observation). By about 1600, the sustained winds measured 25 knots, and the maximum wind gusts were 41 knots. During these times, the wind direction captured from the Shock Trauma Center's sensor was from the west.

Table 6. Results of National Weather Service's postaccident assessment

NWS Finding	Recommendation
1. Atmospheric conditions evolved rapidly during the early to mid-afternoon hours over central Maryland, becoming more unstable than forecasters expected. This supported development of showers and thunderstorms, which moved east-southeast into the Baltimore area.	**1a**. The WFO Baltimore-Washington Meteorologist-in-Charge and Science and Operations Officer should engage all WFO forecasters in a detailed analysis of the evolution of atmospheric conditions on March 6, 2004, related to events of the day at the start of the 2005 convective season. This effort should be conducted as a local training exercise/workshop. **1b**. A related local exercise during or after the activity in recommendation (a) is for WFO management to document local techniques to facilitate operational analysis at the WFO throughout the process of routine forecast development and formulation.
2a. During this event, forecasters relied mainly on data available in their workstations. New data sources take time and resources to integrate into the workstations. Accessing and integrating data from an adjacent computer can be cumbersome and precludes optimum use of data during fast-breaking events. **2b**. Forecasters were able to make only limited use of the complementary surface observations along the Interstate 70 corridor as thunderstorms moved through that area. Even though observations from these private and non-Federal sites were taken every 15 minutes, only half-hourly data were available to NWS forecasters through their workstations. Also, forecasters have noticed issues with the accuracy, availability, and reliability of data from some complementary data sources.	**2a.** NOAA's NWS should review its procedures and capabilities for integrating complementary data into workstations to achieve optimum use of the data available. Special efforts should be made to incorporate all available data and information, including data from government (Federal, State, and local), private sector and academic networks. **2b**. NOAA's NWS should explore ways to make maximum use of complementary data sources during high-impact, especially hazardous events, and to work with potential partners to improve the quality and availability of such data.
3. Forecasters were unable to validate velocities observed on radar with groundtruth reports. The impact of high winds along the Interstate 70 corridor was minimal, resulting in no damage reports from spotters or law enforcement officials. Timely wind gust information from complementary data sources was not available to forecasters.	**3.** WFO Baltimore-Washington management should plan a local training program/workshop for WFO staff focused on improving integration of groundtruth in short-term forecast and warning operations.
4. Forecasters relied mainly on data from their collocated WSR-88D at the WFO Baltimore-Washington. While they did interrogate some TDWR data on a separate computer, they worked less with the Dover Air Force Base WSR-88D. The Dover 88D was farther away, but in this specific set of circumstances, it was better situated to depict base velocity data.	**4.** Eastern Region Headquarters should support a local training exercise for WFO Baltimore-Washington staff between the WFO Meteorologist-in-Charge, the Science and Operations Officer, and the NWS Warning Decision Training Branch based on this event to address optimum use of data from multiple radars.
5. In spite of display limitations, TDWR data showed excellent potential for integration into WFO short-term forecast and warning operations.	**5.** NOAA/NWS should consider ways to accelerate the current NWS-Federal Aviation Administration TDWR data integration project, providing WFOs data from TDWRs within their areas of responsibility.
6. Complementary data from non-NOAA/NWS observation networks could help in the forecasting and warning process.	**6.** NWS should explore options for getting timely, accurate complementary data from non-Government sources.

7. While staffing was at normal levels for a Saturday and sufficient to manage events of the day, had day-shift forecasters been more concerned about the potential impact of the advancing storms and remained on duty, the additional staff might have been able to retrieve additional groundtruth information.	**7**. WFO Baltimore-Washington should investigate slight adjustments in shift times, especially focused on midday workload during the convective season and when indicated by specific environmental conditions.
8a. Prior to 1549, there was no forecast of thunderstorms or wind gusts exceeding 25 mph for the Baltimore area. Forecasts were based on the expectation that showers would not intensify in an air mass characterized by a drying trend and downslope winds. **8b.** Beginning with a short-term forecast at 3.49 p.m. through the special marine warning at 4.05 p.m., forecasters were in a reactive mode, working from radar data and observations from ASOS sites at Baltimore-Washington International Airport and Reagan Washington National Airport. **8c**. Even with automated dissemination of forecast and warning information and excellent NWR coverage of the Baltimore area, short-term forecasts of 45 mph gusts, and a special marine warning were not available to mariners before winds exceeded 45 mph in the harbor. A small craft advisory had been in effect since the previous day.	**8**. As part of local training exercises/workshops relative to this event contained in recommendations 1, 3, and 4, the WFO Meteorologist-in-Charge, and the Science and Operations Officer should engage WFO staff in establishing operational practices aimed at improved and more frequent event-driven products and information.
9. Rebroadcast of NWS marine forecast and warning information via local U.S. Coast Guard radio can take up to an hour.	**9**. Baltimore-Washington WFO staff should work with local Coast Guard officials to develop techniques to improve timely delivery of marine advisory and warning information on Coast Guard radio in the Baltimore Harbor area.

Weatherbug Network

Seaport Taxi was a subscriber to WeatherBug®, a Web-based source of neighborhood weather, severe storm alerts, and radar and camera images available to personal computer users. Headquartered in Gaithersburg, Maryland, WeatherBug® has over 7,000 tracking stations and more than 1,000 cameras networked together nationwide via high-speed Internet. In Maryland, WeatherBug® has more than 300 sensor locations. NWS forecasters can access WeatherBug® data on their workstations; however, officials indicated that because of timeliness and quality control issues with the data, its use is limited. The Seaport Taxi office manager indicated that on the day of the accident, she did not hear the distinctive beep emitted by her computer when WeatherBug® issues a weather announcement.

Medical and Pathological Information

Medical Findings

After the *Lady D* capsized, most of the vessel's occupants were in the water between 5 to 15 minutes, based, in part, on survivor interviews and a reconstructed timeline. The three victims (2 adult women and 1 child) freed by the LCM-8 were recovered at 1617, about 19 minutes after the capsizing. According to the Coast Guard situation report, the area water temperature in the Patapsco River was 44° F and the air temperature was 66° F.[37]

Twenty-two of the *Lady D*'s occupants recovered on March 6 were transported by ambulances to local hospitals in Baltimore, including Johns Hopkins Bayview Medical Center, Johns Hopkins Hospital, Mercy Medical Center, and the University of Maryland Medical Center.

Five passengers, ages 6 to 62, suffered fatal injuries. Two people died in the hospital, and divers retrieved the bodies of three accident victims from the river on March 14 and 15. Records of the general postmortem examinations performed by the Office of the Chief Medical Examiner, State of Maryland, indicate that all deaths resulted from drowning complicated by hypothermia.

The four serious injury victims were passengers who required hospitalization because of injuries suffered at the accident scene or medical complications that occurred at the medical facility. Three adults, ages 55 to 59, were transported to Johns Hopkins Hospital, where one woman required surgery for a shoulder fracture and dislocation. Her husband, also a passenger on the water taxi, experienced chest pains while at her bedside and was admitted for observation. Another woman suffered palpitations while in the emergency room and subsequently spent 3 days in the hospital. An 8-year-old child who almost drowned and went into cardiac arrest was transported to the University of Maryland Medical Center–Pediatrics, where she was admitted for 25 days before being transferred to a rehabilitation center in Virginia.

Twelve people, including the 2 crewmembers and 10 passengers, sustained minor injuries, mostly abrasions, lacerations, and contusions. The vessel master sustained a contusion on his left leg requiring evaluation for fracture and minor cuts on his palms. The mate was treated for hypothermia and diagnosed with pneumonitis. He was discharged after an uneventful night of observation. One passenger suffered a muscle strain pulling other accident victims out of the water onto the overturned boat. Another passenger sprained his ankle when it became caught on something in the boat and he pulled it free.

Toxicological Testing

Regulatory Requirements. Title 46 CFR Part 4 stipulates that the marine employer shall ensure that toxicological specimens are collected as soon as practical from

[37] The aspects of cold exposure survival appear in the "Survival Factors" section of this report.

an individual on board the vessel "who is determined to be directly involved in a serious marine incident."

Postaccident Testing. The University of Maryland Medical Center took blood samples from the *Lady D*'s crew and passengers for analysis as a matter of routine emergency treatment. When the master was admitted to the emergency room, at 1759, he informed the medical technicians that because of the accident, he had to submit samples for toxicology screening. He provided both urine and blood samples at 1841. The medical center laboratory analysis indicated that the master's screens were negative for drugs and alcohol. The medical center obtained a blood sample but no urine sample for testing from the mate at 1754. His blood was not screened for drugs.

The Safety Board subpoenaed the specimens taken from the master and the mate by the medical center for further testing. The medical center, pursuant to the subpoena, provided the master's blood and urine specimens and the mate's blood specimen to the Federal Aviation Administration's Civil Aerospace Medical Institute (CAMI) in Okalahoma City, Oklahoma, for testing. The CAMI report indicated no positive results for alcohol or legal or illegal drugs, including amphetamine, opiates, marijuana, cocaine, phencyclidine, benzodiazepines, barbiturates, antidepressants, antihistamines, meprobamate, methaqualone, and nicotine.

At the request of the Coast Guard, the mate and the master provided samples for drug testing on March 8 and March 10, respectively, at the Concentra Medical Center in Baltimore. The samples were sent to the American Toxicology Network laboratory in Memphis, Tennessee, for analysis. The results of the drug tests were negative.

Survival Factors

Aspects of Survival in Cold Water

The latest update to the *U.S. Coast Guard Addendum to the National Search and Rescue Supplement*, issued January 5, 2006, includes guidance for identifying the four stages of cold-water immersion in which death can occur. The guidance is based on the Cold Exposure Survival Model (CESM) developed by Canada's Defense and Civil Institute for Environmental Medicine for use in predicting survival times for cold air exposure and cold water immersion. The CESM predicts functional time and survival times based on cooling of the body's core,[38] and on an individual's physical characteristics, clothing, and weather and sea conditions. The stages are listed below.

[38] CESM is strictly a hypothermia model and does not include the effects of dehydration, injuries, medications, drugs, alcohol, sleeplessness, and circadian hormonal cycles.

- *Initial Immersion Cold Shock*: Death occurs within 1 to 3 minutes of immersion. Sudden immersion in water colder than 59° F stimulates a large gasp response that may be followed by hyperventilation plus an increase in blood pressure and heart rate, which ultimately causes respiratory or cardiac problems.
- *Cold Incapacitation*: Death occurs within 5 to 30 minutes of immersion. The body's natural attempt to preserve core body temperature by diverting blood from the limbs causes muscular failure, which in turn, causes the person to lose the ability to swim, maintain position, or use his hands.
- *Hypothermia*: Occurs within 20 to 30 minutes of immersion. Continued heat loss eventually results in a decrease in core temperature that adversely affects the heart, lung, and brain. The rate of cooling depends on water temperature, body metabolism and fatness, and external insulation. Hypothermia will progress until shivering stops and unconsciousness occurs.
- *Circum-Rescue Collapse*: Can occur immediately before, during, or from minutes to several hours after the rescue effort. The anticipation of imminent rescue causes a decrease in the output of stress hormones, which may result in a drop in blood pressure that results in fainting and drowning. Also, pulling a victim out of the water in a vertical position removes the "hydrostatic squeeze"[39] on the extremities, which results in decreased blood pressure that causes stress that may induce cardiac arrest.

At the time and in the area of the capsizing, the water temperature was 44° F. As noted earlier, all fatalities resulted from drowning complicated by hypothermia. Three accident victims were trapped inside the overturned vessel about 20 minutes and floated free when the LCM-8 lifted the side of the *Lady D*. Of these, one was pronounced dead upon arrival at the hospital, one died within 72 hours, and the third, a child, almost drowned and suffered cardiac arrest.

City of Baltimore Consolidated Communication Center

According to information provided by the BCFD, in 1995, the City of Baltimore contracted the design, construction, and installation of a state-of-the-art radio and computer-aided dispatch system to better coordinate the response to major emergencies. The consolidated communications system, located at the BCFD's Emergency Communications Center, links the fire department, the police, and the public works department, permitting a single call to 911 to generate a multiagency response. The shared system ensures communication compatibility among all City public safety agencies, which, in the event of a major emergency, permits an incident commander to share

[39] Hydrostatic squeeze refers to the pressure exerted by an external fluid, in this case, the water in which a person is submerged. For example, at 3 feet below the surface, the external pressure is equivalent to nearly 80 millimeters of mercury, which is the typical pressure in the blood vessels of the extremities during the relaxation phase of the heart cycle. Once the water pressure is removed, there is substantially increased blood flow out to the extremities, decreasing core blood pressure.

information with other response agencies, track the dispatch and location of assets such as emergency medical service (EMS) units, and so forth.

Response Assets for Marine Incidents

The Coast Guard has Federal jurisdiction over the Patapsco River because it is a navigational waterway and is used for interstate and international commerce. The State of Maryland has granted jurisdictional authority over the waters surrounding the City of Baltimore, including the Baltimore Harbor waterways, to the BCFD and the BCPD.

The BCFD's Marine Division consists of 37 officers and crewmembers and four vessels, which operate out of the fireboat station at Fort McHenry. The BCPD's marine unit has five vessels to accomplish its missions.

Response of Assets to Lady D Capsizing

At 1558, Navy reservists and others witnessed the *Lady D* overturn and immediately notified 911 (the Emergency Communications Center) of the accident via cellular and landline telephones. The communications center's system dispatcher, in turn, alerted the BCPD and then the BCFD of the accident. Before the BCFD dispatcher could order that agency's marine assets to respond, a BCFD marine pilot on duty at the fireboat station notified the dispatcher that he had witnessed the capsizing. Meanwhile, the Navy reservists had assembled a rescue team and launched an LCM-8, which was the first to arrive at the accident site. By 1603, the BCFD dispatcher had ordered various marine and shore-based assets totaling 43 rescue and medical personnel to respond. Shortly thereafter, the BCFD battalion chief had established a shoreside incident command site and assumed control of the operation. Other State and County assets from Maryland subsequently responded, including a State police search helicopter.

BCFD fire/rescue [boat] No. 1 reached the scene immediately after the Navy Reserve LCM-8, and the BCPD vessel arrived shortly thereafter. The crews on the BCFD and BCPD marine vessels coordinated the rescue effort with the Naval reservists, who had already begun to transfer passengers and crewmembers to the LCM-8. Five reservists had entered the water to rescue those trapped in the deckhouse. The reservists transferred two passengers, one of whom appeared to be in cardiac arrest, to the BCFD boat, which took the accident victims to paramedics waiting shoreside. Meanwhile, the BCPD marine unit crew was successful in extricating an unconscious passenger from the water taxi, whereupon they immediately proceeded toward the pier to turn the passenger over to waiting paramedics. While en route to shore, the police marine crew performed CPR on the victim.

Meanwhile, about 1616, watchstanders at Coast Guard Sector Baltimore, located about 5 1/2 nm from the accident site, learned of the capsizing while routinely monitoring radio traffic on VHF channel 16. Shortly thereafter, at 1617, Seaport Taxi notified the Coast Guard of the accident after company officials determined that the *Lady D* had capsized.[40] Coast Guard personnel then activated the SAR alarm and contacted the BCFD dispatcher, who advised them that four rescue vessels were already on scene. The BCFD advised the Coast Guard of the recovery progress, and the Coast Guard immediately ordered a muster for the dispatch of three utility boats and one helicopter to assist. The first vessel was underway by 1625.

By 1633, the Navy reservists had retrieved the remaining survivors from the overturned pontoon vessel and were transporting them to Naval Reserve Center Baltimore, where a triage team had been assembled to administer aid. From the center, the accident victims were transferred to EMS personnel who transported them by ambulances to local hospitals for further examination and treatment, as necessary.

The first Coast Guard vessel arrived on scene at 1637, and its personnel received an update on the status of the *Lady D*'s occupants from the rescuers already at the scene. Responders accounted for 22 victims within an hour of the accident.

On-scene personnel then established a search for the three remaining passengers, aided by the Coast Guard's second and third utility boats, which arrived at 1657 and 1916 respectively. The search helicopter arrived at 1725. According to BCFD logs, the incident commander relegated the search effort to a recovery operation on March 7. The bodies of two victims were subsequently recovered on March 14 and the body of the last victim was recovered on March 15.

Tests and Research

Safety Board's Stability Study

Following the accident, the Safety Board contracted with Alion Science and Technology, JJMA Maritime Sector, to conduct a study evaluating the intact static and dynamic stability of the *Lady D*.[41] This section first summarizes some basic concepts related to intact vessel stability and then discusses the tasks and modeling variables in the Safety Board's contract study. For a more detailed and illustrative description of vessel intact stability, refer to appendix B.

Stability Concepts. For almost every type of vessel, the vertical center of gravity (center of mass) of the vessel is directly above the vertical center of buoyancy (center of water volume displaced). When the center of gravity and the center of buoyancy are vertically aligned, the vessel is in static equilibrium, typically without any angle of heel. As the vessel heels to one side, the center of gravity shifts to the side as a function of the angle of heel. During the heeling action, the center of buoyancy moves to the side more rapidly than the center of gravity does. The resulting difference in vertical alignment, called the "righting arm" (usually expressed as GZ), creates an imbalance that gives the

[40] Federal regulations at 46 CFR 4.04, "Notice of Potential Vessel Casualty," require that a vessel owner, charterer, managing operator, or agent immediately notify the Coast Guard (district rescue coordinator center or nearest SAR authority) if there is reason to believe a vessel is lost or imperiled.

[41] Intact stability assumes no damage or flooding to a vessel. Static stability is a measure of a vessel's stability characteristics in calm water. Dynamic stability refers to a vessel's motions and response to external forces such as wind and waves.

vessel the tendency to right itself. The GZ times the vessel displacement is the righting moment that resists whatever moments work to heel the vessel over, such as passenger movement or wind forces.

A family of righting arm curves can be developed to analyze the stability of a vessel. Typically, GZ is equal to zero at zero heel, and it increases as the heel angle increases. However, the rate of increase in GZ with heel angle gradually diminishes until it reaches a maximum value at some angle. This is called the angle of maximum righting arm. As the angle of heel increases beyond that point, the GZ decreases until at some point it becomes zero. This point, called the angle of vanishing stability, is the angle at which the center of gravity becomes outboard of the center of buoyancy. After that point, the vessel will continue to heel under its own weight until it capsizes.

A righting arm curve represents a single draft (displacement), so it is usually expressed as a distance (GZ) rather than a moment, because the force component (displacement) of the righting moment is constant. From a physical perspective, it is the moment that provides the righting force. The area under the righting arm curve (foot-degrees) is called "righting energy" in naval architecture convention. The energy expressed by the righting arm curve is reserve energy that gives an indication of the vessel's ability to resist overturning forces and moments such as the effects of waves, steady winds, wind gusts, and other dynamic influences.

Study Tasks. The Safety Board's contract study involved the following seven tasks:

- Task 1: Assess the stability calculations for the *Lady D* and sister vessels performed to show compliance with Coast Guard passenger vessel stability regulations. Determine the adequacy of relevant data to successfully complete a more rigorous analysis of the static and dynamic stability.
- Task 2: Perform a static stability analysis of the *Lady D* at the time of the capsizing using current regulations.
- Task 3: Evaluate the dynamic effects of wind (steady state and gusting), passenger and crew loading and movement, wave action, and any other relevant conditions, and the interrelationships of these dynamic effects on the stability of the *Lady D* that may have contributed to its capsizing.
- Task 4: Prepare a 3- to 5-minute computer animation video showing the capsizing event.
- Task 5: Examine the dynamic response of the vessel *Lady D* when loaded to its maximum safe number of passengers, as determined by applying current stability criteria under similar environmental conditions, to provide some measure of assurance that the static stability criteria provided in Federal regulations is adequate.
- Task 6: Evaluate the intact stability for the *Lady D* as configured on the day of the accident using the following loading conditions:

* Meeting the PSST at 46 CFR 178.340 (carrying 14 persons weighing an average of 140 pounds).

* Meeting the COI (carrying 25 persons weighing an average of 140 pounds).

* Meeting the actual capsize condition (carrying 25 persons weighing an average of 168.4 pounds).

- Task 7: Evaluate the intact stability of the *Lady D* as configured and loaded on the day of the accident when subjected to 30-, 40-, and 50-knot winds acting on the vessel's beam.[42]

The absence of reliable mass properties data on the *Lady D* made it necessary to calculate the vessel's weight and center of gravity. Because neither the owner nor the shipbuilder could provide engineering drawings and most of the vessel deckhouse was missing, the vessel weights had to be estimated. To establish the weight and center of gravity needed to perform the static stability analysis, the boat dimensions were collected with the vessel out of water, and freeboards were measured while the vessel was afloat.

Using Creative System's "General HydroStatics" computer stability software, the static stability analysis of the *Lady D* (task 2) showed that the vessel did not meet the current requirements of 46 CFR 178.340 for pontoon vessels operating in protected waters[43] with 25 (140-pound) passengers, as shown on the vessel's stability letter issued on March 28, 1996. The vessel failed to meet the minimum criteria for adequate stability in both transverse and longitudinal directions. The contractor also performed an analysis of the vessel as loaded at the time of the accident, that is, using an average passenger weight of 168.4 pounds. Again the vessel failed to meet the stability criteria.

Current static stability regulations do not address the effects of wind on pontoon boats. The stability study evaluated the ability of the *Lady D* to withstand a 40-knot beam wind. The evaluation assumed the load the vessel carried at the time of the accident, using passenger weights gathered from witness interviews and hospital records. The average passenger weight was 168.4 pounds. Assumptions were made regarding the vessel's profile because the deckhouse was missing. Under the assumed conditions, the pontoon boat did not capsize from a 40-knot wind acting directly on the side of the vessel. In the simulation, the vessel heeled to about 6°, with slightly less than 2 inches of freeboard remaining, but it remained upright. The calculations did not consider the dynamic effects of vessel motion, wind gusts, waves, or the movement of passengers aboard the vessel.

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[42] Wind variables for the contract study were based, in part, on the data captured by Digiwx and TDWR systems.

[43] According to Federal regulations at 46 CFR 175.400, "Protected waters is a term used in connection with stability criteria and means sheltered waters presenting no special hazards such as most rivers, harbors, and lakes, and that is not determined to be exposed waters or partially protected waters by the cognizant OCMI."

The motion of a floating vessel subject to the forces of wind and waves can be simulated using computer programs that model the physics of the system and calculate the response of the vessel to forces applied by the environment. The wind and the waves are treated as random variables modeled in terms of energy spectra. In this case, a wind spectrum is chosen to establish the limits of the wind conditions at the time of the accident, and a wave spectrum is developed based on the wind spectrum and the fetch[44] over which the wind generates waves.

For the *Lady D* analysis, the wind and waves were assumed to be unidirectional. The spectra were used to generate random wind and wave sequences that were applied to a computer model of *the Lady D*'s hull with the mass properties calculated previously. The exact motion of the vessel was computed as a response to the unique wind and wave profiles, as well as to the initial conditions (position and roll motions) of the vessel that were also random variables. The initial motions of the vessel and the exact wind and wave forces that led to the capsizing are unknown. The simulation represented what the vessel response would have been under the assumed conditions. The analysis produced different results even for minor changes in the initial conditions and the random profiles of wind and waves. Therefore, to identify a trend, such as the tendency to capsize, the simulation was repeated several times to model the variability in the vessel's response to the random inputs.

To complete task 3, the contractor used naval architecture software and analytic methods to simulate the dynamic effects of the wind and wave conditions acting on the vessel. The environmental model used in the simulation assumed a 1.25-foot wave chop at a peak period of 3.0 seconds and a 25-knot steady wind gusting to 42 knots from 300° true.[45] The dynamic simulation, using AQUA Drift[46] simulation software, was run 20 times and the vessel capsized in every case. In all simulations, capsizing occurred within 1 minute.

Task 5 required additional static stability analysis to determine the maximum safe passenger load. The static stability analysis showed that the maximum safe loading condition for the vessel was 14 persons based on the Coast Guard stability standards in 46 CFR 178.340, which assume an average passenger weight of 140 pounds. Dynamic testing with the 14-person load showed that the vessel could capsize if the port beam was exposed to wind and waves for a substantial period. When the beam was exposed for 30 minutes, the vessel in the 14-passenger condition capsized in 9 of 40 cases. In both tasks 3 and 5, the calculations did not consider the dynamic effects of passenger movement (voluntary or involuntary) on board the vessel or the vessel's heel during a turn. The simulations did not account for corrective action, such as changing heading, that the vessel operator could take.

[44] Wave height, length, and period depend upon such factors as wind speed, how long the wind has blown, and fetch, that is, the straight distance a wave has traveled over the water's surface.

[45] The assumed wind and wave conditions were based on witness interviews, photographs taken shortly before the accident, and meteorological data from 1550 to 1600.

[46] AQUA is a suite of ship dynamics software. AQUA Drift, a subprogram of the suite, is a Computational Fluid Dynamics program that solves ship motion problems as a time history by calculating the hydrodynamic and aerodynamic response of a moving vessel subjected to waves, wind, and current.

Tasks 6 and 7 documented the *Lady D*'s loss of stability as measured by reduced righting energy while total passenger load and wind speed increased. (See table 7.)

Table 7. *Lady D* righting energy under different loading cases

Loading Case	Total Load (pounds)	Reserve Righting Energy at Different Wind Speeds (foot-degrees)		
		30 Knots	40 Knots	50 Knots
14 people at 140 pounds each	1,960	37	28	17
25 people at 140 pounds each	3,500	17	10	4
Accident condition	4,210	6	2	None *

* In the actual loading condition at a 50-knot wind speed, the vessel would capsize as the heeling moment exceeds the vessel's static righting moment.

Vehicle Performance Reconstruction

Safety Board engineers amassed evidence from a variety of sources to reconstruct the accident timeline and vessel position before and after the capsizing. Two digital photographs taken by a passenger were used to estimate vessel position and heading as a function of time during the accident voyage. The true camera bearing was reconstructed using uniquely aligned landmarks that were visible on the horizon of each photograph. Foreground data in each photograph, vessel geometry, and the passenger's known seating location were used to establish the camera bearing relative to the vessel bow. The vessel's heading was then calculated based on the true camera bearing and the camera's bearing relative to the vessel bow.

Time-encoded data from the digital photographs were used to locate the photo sequence on a master event time line and to document the position and heading of the vessel before it capsized. Vessel position was estimated using the intersection of the two true camera bearing lines. The two source photographs were taken 11 seconds apart; however, water taxis are relatively low-speed vessels, so the position could be estimated reasonably accurately.

Additional vessel position and heading data were established based on the eyewitness accounts of Navy Reservists, digital photographs taken by Navy personnel participating in rescue efforts on the LCM-8 vessel, and a digital photograph provided by the BCFD.

Other Information

Postaccident Actions by the Coast Guard

Stability Proof Test of Similar Vessels. Following the capsizing, Coast Guard Sector Baltimore ordered the *Lady D*'s sister vessel, the *Patricia P*, and a pontoon vessel of similar size, the *W. B. Morgan*, to cease carrying passengers until a PSST of the vessels could be completed. The testing by the Coast Guard marine inspector, conducted on April 14, 2004, and witnessed by Safety Board investigators, determined that the maximum number of people that the *Patricia P* and the *W. B. Morgan* could carry was 15 and 16, respectively, rather than 25 as indicated on the vessels' COIs. In both tests, the inspector used the testing conditions listed in 46 CFR 178.330, which assume a weight per person of 140 pounds given that the vessels operated exclusively on protected waters and that the passenger load consisted of men, women, and children. Following the test, the Coast Guard deactivated the vessels' COIs at the owner's request.

Based on the PSST findings, the MSO for Coast Guard Sector Baltimore ordered a review of the COIs for all pontoon passenger vessels in the operating area and, where necessary, adjusted the number of passengers permitted. Coast Guard Sector Baltimore used the weight criterion of 140 pounds per person specified in the regulations in making the adjustments.

In response to questions raised by the Safety Board and concerns about the results of the tests conducted by Coast Guard Sector Baltimore, Coast Guard headquarters sent a memorandum to the agency's field units requesting data on all inspected pontoon vessels in their areas. After receiving and analyzing the information, Coast Guard headquarters provided the field offices with a summary of findings, including comments from the field offices. The summary section pertaining to stability tests indicates, among other findings, that most units understood and applied the pontoon stability test as appropriate. Several field offices had suggested raising the weight allotted per passenger in the stability test to 160 pounds for protected waters to more accurately reflect the current size of an average American.

Coast Guard headquarters subsequently issued a memorandum to the field offices containing guidance addressing some of their concerns and questions. The memorandum conceded that Americans are heavier today, but stated that the weight allowance

> was derived for vessels operating exclusively on protected waters and assumes a mix of women, children, and…men. It's what we have in the regs [regulations]; it's what we have to use. Remember, the simplified tests (conventional or pontoon) are conservative in nature. Some of the conservative factor will "make up" for a weight per passenger that doesn't seem to accurately represent the average American.

Pontoon Vessel Stability Project. According to Coast Guard officials, the headquarters memorandum issued to field offices after the *Lady D* capsizing became the first phase in a multiphase action plan designed to evaluate and improve the current pontoon vessel stability process. (See table 8.) A discussion of several completed action items follows.

Table 8. Action items in Coast Guard pontoon stability project

Action Item
1. Query field to determine size of pontoon vessel fleet.
2. Review casualty data to identify other casualties involving pontoon vessels. Include analysis of recreational vessels if data is available….
3. Provide support and document activities to field units as requested and necessary to ensure appropriate tests are conducted and correct procedures followed.
4. Evaluate current pontoon stability process, including determination of limitations of the current test, a comparison of righting arms/energy vs. a conventional hull (classic naval architecture and challenge to the assumption that initial stability predicts adequate dynamic sea keeping) and a validation of "checks" put out to the field in the feedback/"interim guidance."
5. Analyze alternate stability tests for pontoon vessels (American Boat and Yacht Council, International Organization for Standardization) to provide comparison with current pontoon stability test and include pros and cons of use of these alternate tests.
6. Suggest/recommend appropriate use of current (or other) test with more guidance on handling vessels of unusual proportion and form, of a particular length to beam ratio (if appropriate), or calculation of the number of passengers.
7. Report out on items 4, 5 & 6 above to include recommendations for implementation (such as NVIC, regulatory change).
8. Review and advise on other discontinuities noted during the review of current processes.
9. Sharing of report (item 7 above) as a basis for a process action team or other chartered industry/Coast Guard working group (including pontoon manufacturers, designers, American Boat and Yacht Council technical committee) to review results and obtain industry peer review.
10. Design job aid for appropriate pontoon stability test.
11. Analyze subdivision requirements for vessels that carry more than 49 passengers. Compare requirements to current build practices in industry.
12. Review guidance on seasonal restrictions and egress (NVIC 7-91 and NVIC 1-01) for application to pontoon vessels.
13. Review processes at Sector Baltimore.

Policy Letter 04-10. On October 4, 2004, Coast Guard headquarters issued policy letter 04-10 to OCMIs providing guidance for evaluating stability and subdivision requirements of small passenger vessels inspected under 46 CFR Subchapter T. Included with the guidance was a job aid[47] for Coast Guard inspectors to use when witnessing stability proof tests for pontoon vessels operating on protected waters (action item 10). The notes on the job aid state that, for purposes of testing, the weight per passenger should equal 160 pounds, "except when passenger loads consist of men, women, and children." In such cases, the job aid indicates a weight per passenger of 140 pounds "may be used." The job aid required that the inspector include a separate line item for the weight of crewmembers, with the assumed crew test weight equal to 160 pounds per person.

Based on Coast Guard correspondence and the weight standard contained in the job aid for pontoon stability testing, on December 20, 2005, the Safety Board issued Safety Recommendation M-04-4 regarding passenger weight calculations. A full discussion of the recommendation appears later in this section.

[47] A copy of the job aid appears in appendix C.

Pontoon Vessel Stability and Subdivision Study. In February 2005, a study team of Coast Guard personnel initiated an internal study to determine whether the *Lady D*, in a full load condition and operating in protected waters, could meet alternate stability requirements contained in 46 CFR Subchapter S, "Subdivision and Stability."[48] The modeling software[49] calculated the stability of the *Lady D* under two assumed loading conditions: 25 passengers weighing an average of 140 pounds each and 25 passengers weighing an average of 168 pounds each. The alternate stability requirements considered in the project included

- 46 CFR 170.170, "Calculations Required" minimum GM with wind heeling moment [weather criterion],
- 46 CFR 170.173(e)(2), "Criterion for Vessels of Unusual Proportion and Form" (weather criterion), and
- 46 CFR 171.050, "Intact Stability Requirements for a Mechanically Propelled or a Nonself-propelled Vessel" minimum GM with passenger heeling moment [passenger loading criteria for large vessels].

The study team found[50] that with an assumed load equal to 25 persons weighing 140 pounds each, the *Lady D* met the minimum stability criteria in Subchapter S. However, using an assumed load equal to 25 persons weighing 168 pounds each—the actual per-person weight average on the day of the accident—the vessel failed to meet Subchapter S stability criteria, 46 CFR 170.173(e)(2).[51] The criterion not met was minimum energy requirements because the *Lady D* had only 70 percent of the required 10 foot-degrees under the righting arm curve between 0° and the angle of maximum righting arm. The study team concluded that

> [t]he difference between the assumed and actual passenger weight equates to a one-inch change in static freeboard. Given the dynamic environmental factors that affected this casualty, we cannot determine whether this small gain in freeboard/buoyancy would have changed the response of the vessel to the adverse weather and sea conditions reported at the time of the casualty.

The study team further noted

> There are several dynamic factors that affect stability, not all of which are precisely known for the time of this casualty. They are at varying times

[48] Small passenger vessel regulations (Subchapter T) require that pontoon boats be subjected to a simplified stability proof test specified at 46 CFR 178.340. Alternatively, the vessel owner can perform more detailed stability calculations specified in Subchapter S, which applies to all inspected vessels. Regulations in Subchapter T state that failure of the proof test does not necessarily mean that the vessel lacks stability for the intended route, service, and operating condition, but that calculations or other methods must be used to evaluate the vessel's stability.

[49] Creative System's "General Hydrostatics" stability software.

[50] Note that the study findings of the internal staff team are subject to review and may not represent the final position of the Coast Guard.

[51] This weather criterion was developed to better assess overall stability of these types of vessels because their hull forms produce large initial stability but a small range of stability and small righting energy.

> cumulative or canceling, and their effects relative to the vessel's interdependent stability characteristics (i.e., maximum righting arm, area under the righting arm curve, range of stability, and heeling angle) result in an infinite and complex matrix of vessel reactions. Accordingly, we cannot reliably assess the stability required to survive the actual conditions due to the complexity of the calculations and the wide range of introduced error.

April 2005 Analysis of Comparative Stability Standards. On April 28, 2005, the study team completed an analysis of the independent variables affecting pontoon vessel stability that are found in existing regulatory and industry stability standards (action items 4 and 5).[52] The study team reviewed the pontoon vessel simplified stability test variables contained in Subchapter T, Subchapter S, the American Boat and Yacht Council consensus standards, and the International Organization for Standardization (ISO) standards.

The PSST was designed in the late 1960s. At that time, pontoon vessels were fairly simple structures with two pontoons, an open deck, and handrails. The PSST assumed that passenger heeling moments would always be larger than any wind heeling moments. Since the development of the test, pontoon-style passenger vessels have evolved into more complicated structures, sometimes incorporating completely enclosed deckhouses. These modifications raise the center of gravity and dramatically increase the windage area of the vessels. In recognition of this change, the Coast Guard sought to determine whether the pontoon vessel simplified stability study in 46 CFR 178.340 was still appropriate, given the changes in the CFR and modern pontoon vessel design. The April 2005 study therefore addressed the following questions:

- Is the PSST conservative? Do vessels that pass the PSST also meet the other requirements in the 46 CFR Subchapter S? (46 CFR 170.173, 170.170, and 171.050)
- How do the PSST and CFR requirements compare to other standards, such as those of the American Boat and Yacht Council[53] and the ISO[54]?
- Because the PSST only calculates for passenger heel, were wind heeling moments considered negligible when the PSST was developed? If so, should wind heel now be considered in the PSST?
- Has the envelope of pontoon vessel construction been expanded such that pontoon vessels with certain characteristics (small beam/length ratio, initial submergence, or pontoon diameter) are less safe?
- Should the PSST be modified or changed due to modern construction methods and changes in the regulations since the PSST was developed?

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52 "Study on the U.S. Domestic Intact Stability and Subdivision Requirements for Twin Hull Pontoon Passenger Boats Less Than 65 Feet in Length," April 28, 2005.

53 American Boat and Yacht Council Standard H-35, "Powering and Load Capacity of Pontoon Boats."

54 ISO Standard 12217-1: 2002, "Small Craft—Stability and Buoyancy and Categorization—Part 1: Non-Sailing Boats of Hull Length Greater Than or Equal to 6m [meters]."

The parameters examined in the study were as follows:

- Pontoon diameter;
- Distance between pontoon centers;
- Height of center of gravity; and
- Depth of pontoon submergence at full load.

The results of the study showed that pontoon vessels with certain geometries could pass the PSST in 46 CFR 178.340 and still fail other alternative CFR criteria in Subchapter S. That is because wind heel is not negligible for some pontoon vessels, and multihull vessel stability is sensitive to hull dimensions and draft. The existing PSST does not adequately account for these factors. The study recommended restricting the applicability of the PSST to pontoon boats within defined parameters.[55] (See table 9.) This restriction is further supported by analysis of the ISO standard, which shows that vessels with parameters outside these recommendations have difficulty passing ISO criteria for Beaufort 4 conditions[56] (1.5-foot wave heights and wind gusts to 29 mph). The results of the study also show that, under these recommendations, the PSST outlined in 46 CFR 178.340 is the most stringent of the three standards (CFR, American Boat and Yacht Council, and ISO).

Table 9. Boundary conditions for application of pontoon simplified stability test

Parameter	Criteria	Reason
Full load submergence (as a percentage of displaced volume of the pontoons)	Not greater than 50%	Rapid loss of righting energy for vessels with deeper submergence (reduced by 5% due to weight creep)
Full load submergence	Greater than 33%	PSST not applicable to vessels with shallower submergence
Pontoon diameter	Not less than 24 inches	Low overall stability for vessels with smaller pontoons
Distance between pontoon centers	Not less than 6 feet	This minimum value needed to meet protected waters criteria

The study team observed that protected waters are defined in the CFR as sheltered waters presenting no special hazards, such as most rivers, harbors, and lakes. This definition includes no wind or wave restrictions. The study recommended establishing a maximum allowable wind speed of 16 knots (Beaufort 4) in which pontoon vessels can operate or restricting vessels from operating when small craft advisories or warnings are in effect.

[55] The *Lady D*'s pontoons were 24 inches in diameter and spaced 6.1 feet apart. Full load submergence calculations based on the Safety Board contract were as follows: 14 persons at 140 pounds each was 46 percent; 25 persons at 140 pounds each was 53 percent; 25 persons at 168 pounds each was 56 percent.

[56] In 1805, Sir Francis Beaufort developed the Beaufort Scale, which is a method for estimating wind strengths without the use of instruments. It is still used for this purpose as well as for tying various components of weather (wind strength, sea state, and observable effects) into a unified picture.

The study team also found the calculation at 46 CFR 171.050 (minimum GM required for passenger heel) is not relevant to pontoon passenger vessel stability because the passenger weight movements are only half the required weight movements in the PSST. The calculation produces values (numbers of passengers) well beyond the safe carrying capacity of pontoon passenger vessels.

Coast Guard Impact Study. In October 2005, the Coast Guard issued a notice in the *Federal Register*[57] advising that it was conducting a 1-year impact study to determine the effect on the marine industry of increasing the standard allowance for passenger weight and size used to calculate the intact stability of domestic passenger vessels. The impact study resulted, in part, from the Safety Board's Safety Recommendation M-04-4, and from preliminary findings of the Coast Guard's pontoon boat stability study. The notice states that because current passenger weight standards apply to all types of vessels, the evaluation should not be limited to pontoon boats but extend to all small passenger vessels. The Coast Guard engaged a consultant to perform the impact study, which will be completed in two phases and will include the following actions:

- Evaluate potential impacts to the domestic passenger vessel fleet caused by an increase in average passenger weight and size;
- Identify the degree of impact on fleet segments;
- Identify and suggest changes to existing regulations;
- Develop efficient implementation strategies; and
- Provide assistance for the development of draft regulatory changes and associated regulatory analyses, including economic and environmental analyses.

Once the impact study is completed, the Coast Guard will publish a notice in the *Federal Register* advising the public that the study's results are available and requesting comment.

Accidents Involving Pontoon Passenger Vessel Stability.

As part of this accident investigation, the Safety Board asked the Coast Guard to review its casualty records for the purpose of identifying previous pontoon vessel capsizings. The Coast Guard responded that a review of its electronic records indicated that, since 1981, the *Lady D* is the only capsizing casualty involving a commercial pontoon-style passenger vessel.

Previously Issued Safety Recommendation

Recognizing the negative effect of overloading on pontoon vessel stability, in December 2004, the Safety Board issued the following safety recommendation to the Coast Guard:

[57] Vol. 70, No. 207 (October 27, 2005), pp. 61987-61988.

M-04-4

Revise your guidance to Officers in Charge, Marine Inspection, to determine the maximum occupant capacity of small passenger pontoon vessels either (1) by dividing the vessel's simplified stability proof test weight by the per-person weight allowance for an average adult stipulated in Federal Aviation Administration Advisory Circular 120-27D (174 pounds per person, assuming summer clothing and a 50-50 gender mix), or (2) by restricting (at the time of loading) the actual cumulative weight of passengers and crew to the vessel's simplified stability proof test weight.

The Board noted, "Vessels operated in an overloaded condition are exposed to a higher risk of capsizing," and suggested ways to ensure that the certificated load for a vessel is appropriate. The Board suggested that one way to accomplish this would be to increase the average weight used to calculate maximum occupant capacity. The Safety Board proposed that, as an alternative, the weight of persons allowed on board could be limited to the allowable load resulting from the vessel's PSST. The Board suggested that this could be accomplished by painting a load reference line on the vessel's pontoons or by summing people's actual weights as they boarded the vessel.

On April 7, 2005, the Coast Guard responded to the recommendation, stating that it concurred with the premise behind option (1), that is, the need to update the weight standard, but that it did not concur with option (2) "because typical operators of small passenger pontoon vessels do not have a means to accurately determine the cumulative weight of passengers and crew at the time of loading." The Coast Guard noted that the current weight standards "are set out in regulation at 46 CFR 178.330 and extend to all other types of small passenger vessel types"; therefore, necessary changes went beyond a revision of OCMI guidance.

The Coast Guard indicated that it had chartered a workgroup to analyze the passenger weight issue and to assess the potential impacts of regulatory changes. The Safety Board responded on July 26, 2005, stating, "Because the Coast Guard has initiated action to revise the guidance as requested, Safety Recommendation M-04-4 is classified 'Open—Acceptable Response.'"

Following the notice published in the *Federal Register* regarding the impact study contracted by the Coast Guard to determine the effect on the marine industry of increasing the standard allowance for passenger weight and size used to calculate the intact stability of domestic passenger vessels, the Safety Board advised the Coast Guard that Safety Recommendation M-04-4 is classified "Open—Acceptable Response," pending the outcome of the impact study and subsequent planned actions.

Status of Sister Vessels

As discussed elsewhere in this report, because of the issues identified by the Coast Guard in its review of the *Lady D*'s stability, the Coast Guard evaluated the stability of the three purported sister vessels. In the case of the *Patricia P* (formerly the *Fells Point Princess*) evaluation, the Coast Guard witnessed a simplified stability test in April 2004 and determined that it could be certificated to carry 15 persons. However, the owner of the vessel decided to remove the vessel from service and requested that the Coast Guard deactivate the vessel's COI, which the Coast Guard did. The Coast Guard also evaluated the stability of the *Patricia P* based on calculations demonstrating compliance with 46 CFR Subchapter S, and determined that the vessel could carry 20 persons and still comply with Subchapter S.

At the time of the *Lady D* accident, the *Raven* was in seasonal service on the Maumee River in Toledo, Ohio. In June 2004, the Coast Guard performed a PSST on the *Raven*, which resulted in it being certificated to carry 19 persons.[58] The vessel remains in active commercial passenger service on the Maumee River.

The *Misty Harbor II* was removed from active service in August 2001 and put into dry storage at the Susquehanna Santee Boatworks boatyard. After the *Lady D* accident, the Coast Guard evaluated the stability of the *Misty Harbor II* and determined that it could carry 15 persons. Calculations according to 46 CFR Subchapter S indicated that the vessel could carry 21 persons. As of this date, the vessel does not have a COI and remains out of service at the boatyard.

[58] The PSST indicated that 19 persons could be carried. Subsequently, the pontoons were filled with foam to address corrosion wastage. Because of the additional weight of the foam, the allowable person load was reduced to 17.

Analysis

General

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

- Passenger weight criteria for stability assessment;
- Pontoon vessel stability standards; and
- Policies and procedures pertaining to weather operations.

This analysis also examines the factors affecting survivability in this accident.

Exclusions

The Safety Board considered whether such factors as drug (illegal and prescribed) or alcohol use, sleep deficit, or physical impairment might have adversely affected the actions of the *Lady D*'s crewmembers on the day of the accident. The master said that he took no prescription drugs, and toxicological tests of blood and urine samples that he provided within 3 hours of the capsizing were negative for the presence of drugs and alcohol. The mate said that he took Zantac (cymetadine) for acid reflux disease, and toxicological tests of blood samples that he provided within 2 hours of the capsizing were negative for the presence of alcohol. Both men indicated that they did not change their routines in the days before the accident. According to their interviews, the master and the mate respectively averaged about 8 hours and 7 1/2 hours of sleep nightly, consistently at the same times. Thus, they probably were not experiencing a sleep deficit at the time of the accident. The master wore a hearing aid to help discriminate sounds but said he had no problem hearing the radio transmissions from both the senior captain and the taxi office manager. Based on the information provided, the Safety Board concludes that sleep deprivation, alcohol, drugs, and physical impairments were not factors in this accident.

As a matter of routine investigation, the Safety Board examined the *Lady D*'s mechanical systems, principally the steering and propulsion systems, to determine whether they showed deficiencies that might have been factors in this accident. The master of the *Lady D* told investigators that he did not experience any problems with the vessel's propulsion and steering systems during his attempt to transit the waterway but was not able to make headway because he was buffeted by strong winds. The Safety Board's examination of the vessel's hydraulic-type steering mechanism found that it operated normally and showed no evidence of leaks. Manipulation of the steering wheel resulted in it turning smoothly, and operation of the steering control resulted in a full range of movement. The engine motor showed no external indication of failure. The Safety Board therefore concludes that the mechanical condition of the *Lady D*'s propulsion and steering systems was not a factor in this accident.

During the general vessel examination, investigators noted that the aft outboard side of the starboard pontoon had a dent and a small puncture near the waterline. If the damage had existed before the accident, at least some flooding would have occurred in the aft portion of the sectioned pontoon. Such flooding would have caused the pontoon to lose reserve buoyancy, which, in turn, would have reduced the stability of the vessel.

From interviews with various individuals, however, the Safety Board received accounts that support the finding that the starboard pontoon was not damaged before this accident. The water taxi was not operated in a manner that might contribute to damage on the side of a pontoon, particularly at the aft end. The door to the cabin through which passengers embarked was at the bow; consequently, the vessel was docked bow-side to the pier. Seaport Taxi's fleet captain said that he had checked the *Lady D* when he arrived at the marina that morning and noted no damage to the vessel, including both pontoons. Both the master and the mate were required to perform checks listed on a daily log sheet before putting the *Lady D* into operation, and both said that they did not observe any indication that the starboard pontoon might be damaged. The responders from the Naval Reserve center stated that during the rescue effort, they positioned the bow gate of their LCM-8 under one of the *Lady D*'s pontoons and lifted it up in order to free people trapped inside the cabin. The impact of a large structure made of steel with a smaller structure made of aluminum could have caused the dent and puncture in the pontoon.

Investigators found no other significant damage to either pontoon on the *Lady D*. In addition, examination of all other vessels in the Seaport Taxi fleet revealed that their general condition was good and that their pontoons were free of damage such as that found on the hull of the *Lady D*'s starboard pontoon. Thus, both the postaccident interviews and the vessel examinations support the finding that the damage to the starboard pontoon most likely occurred after the capsizing. The Safety Board therefore concludes that examination of the *Lady D*'s hull showed no evidence of preaccident damage.

Accident Analysis

While en route from Fort McHenry to Fells Point, the commercial pontoon vessel *Lady D*, with 2 crewmembers and 23 passengers on board, encountered gusting westerly winds. Despite efforts by the master to maneuver the vessel to a safe haven, he could not control the water taxi in the wind, and the vessel ultimately capsized in the Northwest Harbor, where the West Channel and the East Channel converge. Responding rescuers, including Navy reservists, as well as BCFD and police assets, succeeded in recovering and transporting 22 of the vessel's occupants to local hospitals within less than an hour. The bodies of 3 victims were not recovered until the following week. As a result of this accident, 5 people died, 4 people suffered serious injuries, and 12 sustained minor injuries.

Cause of the Capsizing

The pontoon-style small passenger vessel *Lady D* was built in 1996 and had only been operated in Baltimore Harbor as a water taxi. Its first owner/operator was Baltimore Harbor Shuttle. In 2000, Seaport Taxi, through its parent company Living Classrooms, obtained the *Lady D* and operated the vessel primarily on the company's outer loop route between Fells Point and Fort McHenry. Interviews with the original owner and officials of Seaport Taxi revealed that in the 8 years during which the *Lady D* had transported passengers, the vessel had never experienced any major incidents. In the year before this accident, only one master who had operated the *Lady D* had submitted a daily log report indicating that he had encountered "windy" conditions; however, his report did not indicate that he had been forced to tie up because of the winds. Seaport Taxi records show that the company transported more than 200,000 passengers annually. Thus, the *Lady D* most likely had previously operated with a full load of passengers and crew during both fair and inclement weather but not in conditions like those on the day of the capsizing.

In the case of the master involved in the accident, he had worked for Seaport Taxi for 3 years, primarily on weekends and occasionally on weekdays during the peak season. He had been assigned almost exclusively to the *Lady D* during this time. He stated that he had operated the *Lady D* before in inclement weather and thought that on some occasions he might have been caught in wind gust conditions of 40 to 50 knots. He said, however, that he had never been caught in conditions like those on the day of the accident. In the few minutes before the capsizing, no meteorological sensor in the area captured wind conditions such as those the *Lady D* master said he had previously experienced. The evidence therefore suggests that the master probably incorrectly estimated the wind conditions on previous occasions.

In seeking to determine what on the day of the accident so greatly affected the stability of the vessel that it capsized, the Safety Board found that a combination of factors contributed to the vessel's overturning. Some factors stemmed from errors made in determining the allowable number of occupants in certificating the vessel. Those errors permitted the vessel to operate in an overloaded condition that, when combined with the effects of wind and waves, significantly reduced the stability of the pontoon boat. The investigation also revealed flaws in the Coast Guard's granting of sister vessel status to three similar boats built after the *Fells Point Princess*, including the *Lady D*. These issues are discussed in greater detail in the following sections.

Certification Error

The *Lady D*'s stability problem stemmed from the 1992 simplified stability proof test of the *Fells Point Princess* (later renamed the *Patricia P*), the first of four vessels built over a 10-year period. The test was not conducted in accordance with the PSST protocol as it should have been, but rather with the SST protocol for monohull vessels. Pontoon vessels and monohull vessels have dramatically different stability characteristics. A pontoon vessel's wide base gives it large initial stability. However, a pontoon vessel's range of stability is generally much less than that of a monohull vessel and vanishes quickly as a pontoon begins to submerge when the vessel heels. Consequently, it was inappropriate to use the test protocol for monohull vessels to determine the stability and loading capability of a pontoon-style passenger vessel such as the *Fells Point Princess*.

The test document indicates that passenger heeling moment calculations were based on moving the test load weight from the centerline to one-third the distance to the extreme outboard side of the vessel (the distance needed to achieve the amount of heeling moment specified in the monohull test protocol). The test protocol for the PSST required that the test weight be moved from the centerline to the extreme outboard edge of the vessel, which in the case of the 8-foot-wide *Fells Point Princess* was a distance of 4 feet. Thus, the test did not provide the appropriate heeling moment for determining the maximum number of persons allowed.

As a result of the inappropriate application of the SST protocol on the *Fells Point Princess*, that pontoon vessel was certificated to carry 25 persons based on the 140-pound average weight standard specified in Coast Guard regulations. This average weight standard was developed by the Coast Guard in the 1950s and assumed a mix of men, women, and children.

The three vessels subsequently built by Susquehanna Santee Boatworks, which included the *Lady D*, had the same general size (36 feet long by 8 feet wide) and arrangement and had a superstructure for the carriage of passengers. The Coast Guard granted sister vessel status to these boats because of their similarities and did not subject them to their own stability tests. Consequently, the results of the original vessel's stability certification, which was based on an inappropriate test protocol, were carried through to the other vessels. The Safety Board concludes that the load for which the pontoon vessel *Lady D* was certificated was based on a monohull simplified stability proof test on the *Fells Point Princess*, which was not appropriate for pontoon vessels.

Erroneous Sister Vessel Status

Although the *Fells Point Princess*, the *Raven,* the *Lady D,* and the *Misty Harbor II* were of the same general size, the vessels differed in certain design aspects that affected their load-carrying capability and stability. The most notable difference was in the design of their deckhouses. The deckhouses of the first two vessels constructed, the *Fells Point Princess* and the *Raven,* had large side openings with no windows. The third and fourth vessels in the series, the *Lady D* and the *Misty Harbor II*, were fitted with large glass windows and doors. The postaccident stability analysis of the *Lady D* contracted by the Safety Board estimated that the weight of the *Lady D*'s glass windows and doors exceeded 400 pounds, nearly equivalent to the weight of 3 passengers [400 pounds divided by 140 pounds per person = 2.87 people].

Following this accident, the Coast Guard retested the *Lady D*'s sister vessels, the *Patricia P*, the *Raven,* and the *Misty Harbor II.* The Coast Guard also evaluated the stability of the *Lady D* by direct calculation. The Coast Guard's postaccident testing of the sister vessels revealed that each had different load-carrying capabilities because of their design differences. The first vessel in the series, the *Patricia P* with its partially enclosed superstructure, was found able to carry 15 persons. The *Raven*, which also had a partially enclosed superstructure, was found able to carry 19 persons. The *Misty Harbor II*, with a fully enclosed superstructure, was found able to carry 15 persons. The differences in the vessels, including their occupant capacity, indicates that they were not similar enough to be considered sister vessels.

While researching its records to assist the Safety Board and to conduct its own investigation of this accident, the Coast Guard discovered errors in the stability certification and sister vessel status assignment for the *Lady D* and the other three boats in the series. Coast Guard files show that the *Lady D* did not undergo a stability test but was granted sister vessel status to the *Raven* by the OCMI and certificated for the same passenger load as that vessel based on the approved results of the *Raven*'s stability test. However, Coast Guard personnel could not locate any documentation of a stability test for the *Raven*. They subsequently determined that the *Raven* had never undergone a stability test but had been granted sister vessel status to the *Fells Point Princess*.

Granting sister vessel status to the *Raven*, the *Lady D*, and the *Misty Harbor II* precluded the Coast Guard from discovering that the passenger capacity of the *Fells Point Princess* (and the later vessels in the series) was based on the inappropriate application of the SST on a pontoon vessel. If the Coast Guard had recognized that the *Fells Point Princess* and the other vessels in the series had not been built by the same builder and that the design of the *Lady D*'s deckhouse differed from that of the *Raven* and the *Fells Point Princess*, it may have required that a PSST be performed on the *Lady D*. The results of a PSST of the *Lady D* would have yielded a significantly different allowable occupant load from that of the *Raven* or the *Fells Point Princess*, to such a degree that the Coast Guard probably would have recognized that an error had been made in an earlier test and taken corrective measures. The Safety Board concludes that as a result of inappropriate sister vessel status to the *Fells Point Princess* being granted to the *Raven*, the *Lady D*, and the *Misty Harbor II*, all four pontoon boats had serious deficiencies in stability as a result of the inappropriate stability test used to determine the number of persons allowed on all the vessels. Although it was the *Lady D* that was involved in this accident, the potential risk of a capsize event was substantially the same for all four vessels during their years of operation.

Coast Guard headquarters, after learning of the errors in the vessel files at Coast Guard Sector Baltimore and being informed about the results of the postaccident stability testing of the pontoon vessels in series to the *Lady D*, directed field commanders to "assess their risk" as it pertained to pontoon passenger vessels within the field offices' areas of responsibility. Coast Guard field office personnel subsequently reviewed the files and documents and analyzed the results of stability tests on file to ensure that the "stability conditions" of pontoon passenger vessels were accurate and, where deemed necessary, ordered pontoon vessels to undergo new stability tests. Headquarters guidance to the field offices also provided some examples of defined "Reasonable Operating Conditions," a common entry that is added to the COI for a vessel when it operates in areas where wind and other factors might affect its safe operation. Additional information about postaccident measures taken by the Coast Guard appears later in this analysis, under "Pontoon Vessel Stability Standards."

Passenger Overloading

From interviews and its review of emergency room records, the Safety Board found that the average weight of the *Lady D*'s occupants on the day of the accident was 168 pounds, significantly more than the per-person weight standard of 140 pounds used to verify the allowable number of passengers in stability proof tests. The combination of the excessive number of persons permitted in the original certification and the higher-than-assumed average weight of the people on board the *Lady D* resulted in the vessel being significantly overloaded.

The correctly calculated capacity allowed for 14 persons at 140 pounds each, or 1,960 pounds total; however, the vessel actually carried 25 persons at 168 pounds each, or 4,200 pounds total. The additional weight resulted in the vessel's pontoons being more deeply submerged, which, in turn, caused a reduction in the reserve buoyancy available to resist overturning moments. The Safety Board concludes that the combination of the use of an out-of-date average weight standard for occupants of small passenger vessels and the excessive number of persons permitted in the *Lady D*'s original certification resulted in the pontoon boat carrying a load that reduced its reserve buoyancy and compromised its stability characteristics, which made it more susceptible to capsizing on the day of the accident. The issue of the weight standard is addressed later in this analysis, under "Passenger Weight Criteria for Stability Assessments."

Influence of Weight and Wind on Intact Stability

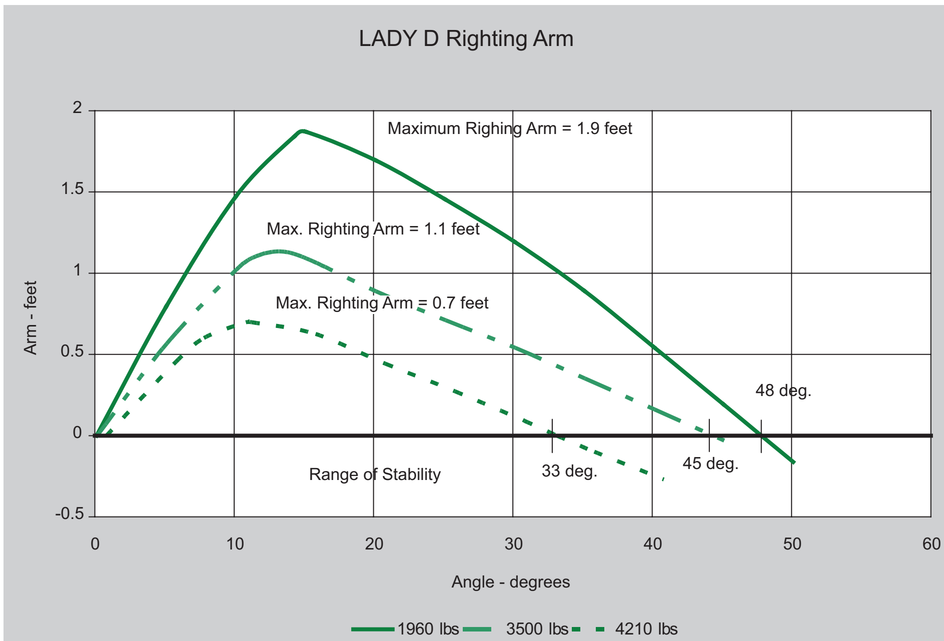
The Safety Board's stability study examined and charted the effects of load and wind on the intact stability of the *Lady D*. Figure 6 shows the charted righting arm curves for the following three load cases, which assume calm waters:

- The first case—14 persons weighing an average of 140 pounds each (1,960 pounds total)—represents the maximum safe load condition allowed for the *Lady D* in accordance with the PSST at 46 CFR 178.340, which would be the test protocol used today to certificate the *Lady D*.
- The second load case—25 persons each weighing 140 pounds (3,500 pounds total)—represents the load allowed under the Coast Guard COI for the *Lady D*, which reflects the inappropriate use of the monohull simplified stability proof test.[59]
- The third loading case—25 persons weighing an average of 168.4 pounds (4,210 pounds total)—represents the *Lady D*'s load condition at the time of the accident.

The charted values show how increasing the load carried by the vessel significantly decreased the maximum righting arm of the vessel and the vessel's range of stability. The maximum righting arm for the vessel in the first load case was 1.9 feet and

[59] The second loading case is somewhat artificial in that it was used only to distinguish between the separate effects of first and third cases (the type of stability test and the heavier weight of contemporary Americans).

the vessel's range of stability was about 48°. In the second load case, the maximum righting arm was 1.1 feet and the vessel's range of stability was about 45°. In the third load case, which was the load condition at the time of the capsizing, the maximum righting arm was 0.7 feet and the vessel's range of stability was 33°. Under these conditions, if the vessel heels beyond a 33° angle of heel, no righting energy remains to bring it back to an even keel, with the result that the vessel will capsize.

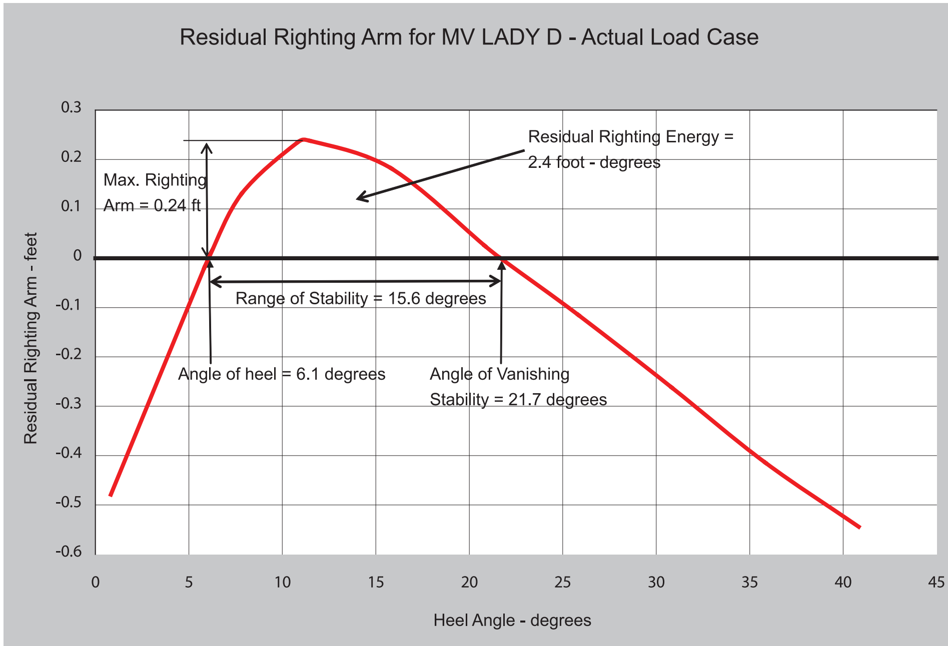


Graphic courtesy of Alion Science and Technology, JJMA Maritime Sector

Figure 6. Righting arm curves for three load cases. The top, solid curve is for the first loading case of 1,960 pounds. The middle curve is for the second case with a 3,500-pound load. The bottom dashed curve is for the *Lady D* as loaded on the day of the accident (4,120 pounds).

The passenger load on the *Lady D* on the day of the accident therefore had a major negative effect on the vessel's intact stability. The weight of the persons on board the vessel increased its draft, which reduced the reserve buoyancy of the pontoons. The reserve buoyancy of the pontoons, especially of the downwind pontoon, is what produced the righting force that could counteract environmental forces that would heel the vessel farther over. Therefore, the loss of reserve buoyancy reduced the ability of the *Lady D* to resist environmental factors such as wind and waves on the day of the accident.

The static analysis of the effect on the vessel of wind alone showed that the force of a 40-knot wind was not adequate to overturn the vessel. Figure 7 charts the impact of a 40-knot wind on the intact stability of the *Lady D* as loaded on the day of the accident. The figure shows the vessel's "residual righting arm," which is the difference between the righting arm for the vessel and the wind-heeling arm. In calm water, a 40-knot wind would heel the vessel over to a 6.1° angle.

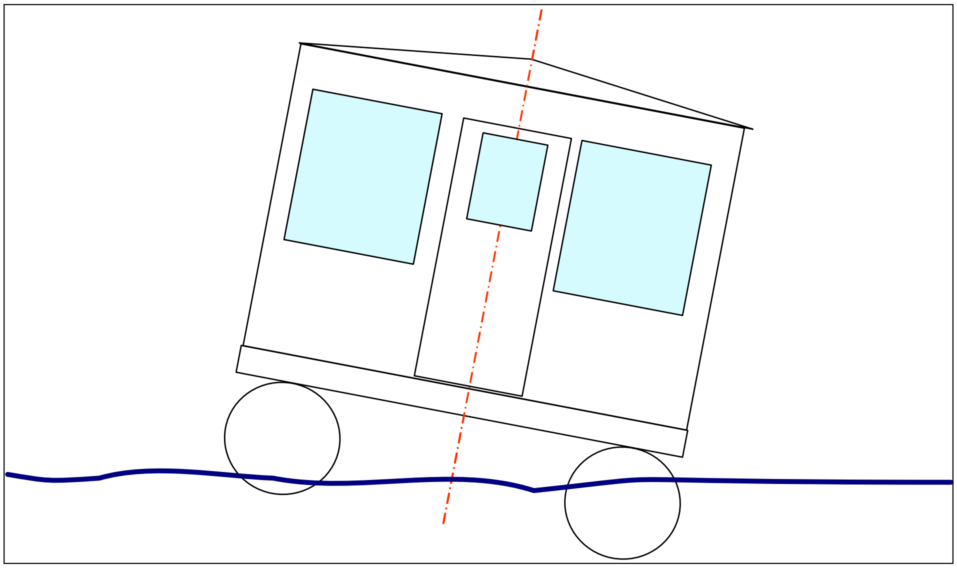


Graphic courtesy of Alion Science and Technology, JJMA Maritime Sector

Figure 7. Residual righting arm for *Lady D* in 40-knot wind.

In the heeled condition, illustrated by figure 8, the *Lady D*'s pontoon on the side opposite the wind was almost completely submerged and had little reserve buoyancy left to counteract additional heeling forces. Thus, considering the *Lady D*'s load and wind conditions on the day of the accident, at an angle of slightly less than 22° of heel, the vessel would have had no reserve righting arm and nothing to prevent it from capsizing. At a wind speed of 40 knots, very little margin remained in the vessel's intact stability to counteract additional dynamic heeling forces. Any additional external force such as a wave hitting the boat, a rapid maneuver by the boat's master, or a shift in the boat's center of gravity due to passenger movements would have been enough to capsize the vessel.

The wave height at the time of the capsizing was about 1.25 feet, and the master was trying to maneuver the vessel to a safe haven. The Safety Board therefore concludes that the *Lady D* capsized as a result of the combined effects of the excessive load it carried and the wind and wave conditions experienced at the time of the accident.



Graphic courtesy of Alion Science and Technology, JJMA Maritime Sector

Figure 8. Sketch of *Lady D* in the heeled condition.

Passenger Weight Criteria for Stability Assessments

Within months of this accident, the Safety Board, after determining the *Lady D*'s total weight load and its detrimental effects on that vessel's stability, issued a safety recommendation to the Coast Guard. That action was warranted because the design of most pontoon-style small passenger vessels makes them particularly susceptible to capsizing when they operate in an overloaded condition. Safety Recommendation M-04-4 asked that the Coast Guard take measures to minimize the possibility that occupant weight load carried on a pontoon passenger vessel would exceed the stability proof test weight.

In its letter to the Coast Guard, the Safety Board suggested that as one method to ensure that the certificated load is accurate, the average weight used to calculate maximum occupant capacity should be increased. The Board cited the per-person weight criterion of 174 pounds used by the Federal Aviation Administration for aircraft loading. The Board suggested that as an alternative measure, the cumulative weight of persons permitted could be limited to the allowable weight load calculated in the vessel's PSST. This alternative measure could be accomplished in various ways, including summing the actual weights of people as they boarded the vessel, or by placing a load reference line on the vessel's pontoons to indicate the total allowed occupant weight.

The Coast Guard concurred, in part, with the recommendation, and provided the Safety Board with an early draft of its multiphase action plan addressing pontoon passenger vessel stability. The Coast Guard chartered a workgroup to analyze the passenger weight issue and to assess the potential impact of regulatory changes in pontoon vessel stability calculations. The workgroup was tasked to review background material and determine the potential impacts of changes to the regulations regarding passenger weight, simplified stability proof tests, and other small passenger vessel stability requirements. Based on the workgroup's plan, the Safety Board classified Safety Recommendation M-04-4 "Open—Acceptable Response" on July 26, 2005.

The Coast Guard announced in the October 27, 2005, *Federal Register* that it was contracting for a study to determine the potential impact on the marine industry that would result from increasing the passenger weight and size standards used when calculating the intact stability of all domestic passenger vessels.

The Safety Board's subsequent investigative work, including preliminary findings in the October 2, 2005, capsizing involving the monohull passenger vessel *Ethan Allen* in Lake George, New York, demonstrate that excessive load due to underestimating the weight of passengers needs to be addressed in the Coast Guard's intact stability criteria for all domestic passenger vessels. The 140-pound weight standard is used in the PSST (46 CFR 178.340), the SST (46 CFR 178.330) for monohull small passenger vessels on protected routes, and the Subchapter S stability calculations for the minimum GM required for passenger heel (46 CFR 171.050). Updating these standards will result in a more realistic assessment of the number of passengers a vessel can safely carry. Considering that statistically representative average passenger weight is subject to change, the Coast Guard should also identify how best to address a test value that may change in the future.

Accordingly, the Safety Board believes that the Coast Guard should revise regulations to require that passenger capacity for domestic passenger vessels be calculated based on a statistically representative average passenger weight standard that is periodically updated. As a result of this recommendation, Safety Recommendation M-04-4 is classified "Closed—Superseded" in this report.

Updating the average passenger weight standard will be a positive step toward ensuring that a vessel is properly certificated for the number of passengers it can safely carry. However, even if the number of passengers permitted is based on an increased average weight standard, the problem persists that a vessel can become overloaded if many of the passengers on board are heavier than the standard. Masters therefore need an easy way of identifying whether the passenger load they are preparing to carry will compromise the stability of their vessels. If a mark were painted on the hull that corresponded to the waterline when the vessel was under maximum approved load, any crewmember could easily determine whether the vessel was overloaded simply by observing the vessel's draft in relation to that mark. The Safety Board concludes that masters need a simple and ready means such as a mark on the hull to determine whether their vessels are overloaded and potentially unsafe. The Safety Board therefore believes that the Coast Guard should identify a method for determining the maximum safe load condition of a small passenger vessel at the time of loading, such as a mark on the side of the hull, and require that the vessel owners implement that method.

Pontoon Vessel Stability Standards

Following this accident, investigations and tests conducted by both the Coast Guard and the Safety Board revealed that some factors affecting pontoon vessel stability are not adequately addressed in existing regulatory standards. The Coast Guard's action plan involves several reviews and studies, some of which are summarized later in this analysis. Early actions involved querying the field offices regarding the number of small passenger pontoon vessels under their purview and advising field commanders to initiate quality checks of stability documents on file. Subsequent actions involved evaluating the current pontoon stability approval process, including determining limitations of the current test and analyzing alternate stability tests for pontoon passenger vessels (American Boat and Yacht Council, ISO) for the purpose of identifying whether and how the existing PSST should be revised.

The stability study contracted by the Safety Board showed that if the *Lady D* had been loaded with 14 or fewer 140-pound persons (a maximum load of 1,960 pounds), the water taxi would have met the static stability requirements for pontoon passenger vessels found in 46 CFR 178.340 (the PSST). However, the PSST does not explicitly address the effects of wind and waves. In this accident, as the *Lady D* proceeded across Baltimore Harbor and the master changed course to make for safe haven, the full strength of the storm struck the vessel on the port beam. The wind gusts and waves rocked the vessel so much that the *Lady D* could not resist the heeling forces and capsized.

Recognizing that the wind or waves were probably factors in the capsizing, the Safety Board tasked its contractor to analyze their role in the *Lady D* casualty. Calculations performed to evaluate the ability of the *Lady D* to withstand a beam wind showed that with a load of 25 persons weighing an average of 168.4 pounds, the vessel had adequate righting moment to resist the static force of a 40-knot wind acting directly on the side of the vessel. In the simulation, the vessel heeled about 6° and had slightly less than 2 inches of freeboard, but it remained upright. The results of the computer simulation to evaluate the dynamic effects of wind and waves on the *Lady D* were dramatically different. The environmental model used in the simulation assumed 1.25-foot waves at a peak period of 3.0 seconds and a 25-knot steady wind gusting to 42 knots on the beam. The dynamic simulation was repeated 20 times to establish a statistical baseline, and the vessel capsized in every case. In all simulations, capsizing occurred within 1 minute. Note that the computer simulation assumed that the heading of the vessel did not change. In reality, a vessel operator would most likely attempt to change the heading of the vessel to avoid a beam wind.

Unlike the SST for monohull vessels, the original PSST developed by the Coast Guard did not include a wind heel condition. Though the Coast Guard acknowledges that it no longer has documentation to explain the genesis of the PSST, officials indicated that they thought an exception to the wind heel conditions had been made for pontoon vessels because early vessels, as designed, did not carry canopies or deckhouses. Under those circumstances, passenger heel, rather than wind heel, was the more critical stability test. Today, however, pontoon passenger vessels such as the *Lady D* have deckhouses that significantly increase a vessel's wind profile and raise its overall center of gravity to the point that its wind heel resistance needs to be evaluated in addition to passenger heeling moments.

The Coast Guard has recognized the evolution in design and configuration of pontoon passenger vessels and addressed the impact of wind heel by issuing to all OCMIs policy letter 04-10, which includes guidance and a job aid for conducting a PSST. The new test protocol includes an additional calculation that evaluates wind heel as a potential limiting condition on vessel stability.

The Safety Board acknowledges that the job aid form developed by the Coast Guard should be easier to use than previous references. The applicability instructions in the job aid should preclude a Coast Guard inspector using the wrong test protocol when overseeing a stability proof test. However, the guidance for the job aid still directs Coast Guard inspectors to use the 140-pound weight standard for passengers in its calculation formulas. As noted earlier in this report, this weight standard is out-of-date and does not reflect the weight of average Americans today.

The various tests that the Coast Guard conducted or contracted for in 2005 as part of its pontoon vessel stability project corroborated many findings in the stability evaluation contracted by the Safety Board. Tests by both the Safety Board and the Coast Guard found that the *Lady D* under a full load condition (25 persons) would not pass the PSST in 46 CFR Subchapter T (small passenger vessels). The Coast Guard's Marine Safety Center (MSC) ran calculations to determine whether the *Lady D* in a full-load condition and operating on protected waters could meet the alternate stability requirements in Subchapter S, an option for stability compliance available to vessel owners. The MSC found that while loaded with 25 140-pound persons, the *Lady D* could meet the minimum stability criteria in Subchapter S. However, under the actual load conditions at the time of the accident, or about 710 pounds over the weight load permitted by standard, the MSC found that the vessel failed to meet the weather criteria in 46 CFR 170.173(e)(2) for vessels of unusual proportion and form. The MSC evaluation, like the Safety Board's contract evaluation, found that the overloaded vessel could not meet the Coast Guard's stability criteria for weather. In its summary of findings, the MSC noted that the *Lady D*'s intact stability was unpredictably affected by the weather and sea conditions at the time of the accident.

A Coast Guard study team subsequently conducted an analysis to determine whether the PSST was still appropriate for modern pontoon vessels, which usually have superstructures that add weight and make the vessel more susceptible to the effects of wind. The analysis was a parametric review comparing stability standards in Federal regulations (the PSST in Subchapter T and criteria in Subchapter S) with those of industry (American Boat and Yacht Council and ISO).

The study team's parametric study observed that the PSST usually produced the most conservative results in calculating passenger loading, but not always. A pontoon vessel could pass the PSST and fail the alternative criteria found in Subchapter S because the effect of wind heel is not negligible for some pontoon vessel designs and because multihull stability is sensitive to vessel dimensions and draft. Some pontoon vessel designs that could meet the static stability criteria in Subchapters S and T would have difficulty meeting the ISO stability standard for wind and waves. This finding was consistent with the results of the Safety Board's contract evaluation, which found that the *Lady D*, while configured to pass the PSST (14 persons at 140 pounds each), could capsize under the dynamic load conditions of wind and waves that existed at the time of the accident.

The study team also found that if certain characteristics in pontoon vessel design (full load submergence, pontoon diameter, and distance between pontoon centers) were limited, the PSST criteria as revised in Coast Guard policy letter 04-10 would be the most stringent of all the pontoon stability standards evaluated. The *Lady D* would not have met the full load submergence criteria in the COI condition (25 persons at 140 pounds each) or the accident condition (25 persons at 168 pounds each). In each condition, the full load submergence exceeded 50 percent. The study also recommended implementing a maximum wind speed under which pontoon vessels could operate in protected waters and revising the average passenger weight standards.

The analyses of the stability of pontoon passenger vessels performed by both the Safety Board and the Coast Guard as a result of the capsizing of the *Lady D* raised safety issues related to Coast Guard pontoon vessel stability standards that need to be resolved to reduce the possibility of this type of accident recurring. The Safety Board concludes that existing Coast Guard intact stability standards for pontoon passenger vessels (the PSST in Subchapter T, "Small Passenger Vessels," and/or the alternative criteria in Subchapter S, "Subdivision and Stability") do not adequately account for the dynamic loading from wind and waves on a pontoon vessel operating on an unrestricted protected route. The Safety Board therefore believes that the Coast Guard should revise the stability criteria for small passenger pontoon vessels for all passenger loading conditions to minimize the potential for capsizing in wind and waves.

Both the Safety Board and the Coast Guard demonstrated that the *Lady D* could not meet the PSST for the carriage of 25 persons. If a vessel fails a stability proof test, the owner must make one or more of the following changes to reduce the heeling moment so that the vessel can pass the proof test: carry fewer passengers, ballast the vessel, or reduce the vessel's wind profile area, if applicable. Coast Guard policy letter 04-10 indicates that if a pontoon vessel does not pass the physical proof test in the PSST, the vessel owner can provide design calculations to the MSC showing that the vessel meets the applicable stability criteria of 46 CFR Subchapter S in each condition of loading. The *Lady D*'s owner therefore could have submitted calculations demonstrating compliance with 46 CFR Subchapter S for 25 persons. The MSC would have approved these calculations for the carriage of 25 persons. Yet, the MSC's February 2005 analysis of the *Lady D* accident indicated that the dynamic factors affecting the *Lady D*'s stability were not precisely known, and, consequently, it could not reliably assess the stability required for the vessel to survive the actual conditions encountered. Therefore, the Safety Board recommends that until such time as the Coast Guard revises the passenger weight standard and the stability criteria used to evaluate small passenger pontoon vessel safety as requested, it should develop interim pontoon passenger vessel stability guidance based on static and dynamic intact stability considerations.

Although the CFR defines protected waters as sheltered waters presenting no special hazards, the definition includes no wind or wave restrictions. OCMIs will often include “Under reasonable operating conditions” as an operating restriction on COIs issued by the Coast Guard. This caveat gives no objective operational guidance to vessel operators for assessing the ability of a vessel to safely operate in wind and waves. The Coast Guard study team in its pontoon vessel stability review recommended that operational guidance be provided on COIs restricting operations in wind conditions not greater than Beaufort force 4 (16 knots of wind) or using the more familiar small craft advisory/warning (observed or forecast winds of 18 to 33 knots). The Safety Board therefore concludes that a Coast Guard endorsement on a vessel’s COI restricting a pontoon passenger vessel to limiting weather conditions would provide definitive operational guidance to a vessel’s operator. The Safety Board believes that the Coast Guard should establish limiting environmental conditions such as weather in which pontoon vessels may safely operate, and list those limiting conditions on the vessel’s COI.

Policies and Procedures Pertaining to Weather Operations

In this accident, NWS meteorologists failed to identify the developing storm conditions in a timely manner and provide the information to mariners in a special marine warning. Seaport Taxi’s weather policy also did not ensure maximum safety of operations during threatening weather conditions. These problems and factors affecting the decision of the *Lady D* master to leave the Fort McHenry dock are discussed below.

NWS Operations

Data captured by various systems near the accident site, including Baltimore Marine Center and BWI airport, showed that at the time of the capsizing (1558 to 1600), the *Lady D* encountered westerly winds gusting about 28 knots (32.2 mph) to 41 knots (47.2 mph), with a sustained wind speed of about 25 knots around 1600. The winds were generated by a thunderstorm moving through the area. Lightning strike data indicated cloud-to-ground lightning strikes in the accident area at the time of the accident. The TDWR at BWI recorded no data indicating that a microburst or downburst had affected the vessel.

In this accident, the performance by the NWS forecasters on duty at the Baltimore-Washington forecast office was adversely affected by their preconceptions about the environmental conditions, which they had discussed with the forecasters they had relieved earlier in the afternoon. The meteorologists’ procedures typically involved monitoring the various data systems available and if they had any cause for concern, comparing the data captured by their own systems and commercial mesonet systems to analyze evolving weather conditions. However, mesonet and TDWR data were not available in a format that they could readily use. Comparing the various data took several minutes, and if conditions warranted issuing a special marine warning, preparing the message took at least 5 minutes.

The meteorologists at the Baltimore-Washington forecast office were slow to respond to evidence of intense storm conditions until the lead forecaster noticed a high wind reading (46 knots) at 1544 at Reagan Washington National Airport. However, their own system data that were available at their workstations had provided sufficient information to have warranted their issuing a special marine warning before the *Lady D* embarked passengers at the dock near Fort McHenry at 1552.

About 1500, LWX Doppler radar images indicated areas of intense weather echoes about 40 miles north/northwest of Baltimore Harbor. The weather radar data also indicated cell movement in excess of 40 knots. At 1514, the LWX Doppler weather radar indicated that the radial velocities (westerly component) to the west of that NWS office were greater than 34 knots at an altitude of 1,500 feet above msl (mean sea level). The forecasters' workstations also displayed surface observations from airport ASOS and AWOS sites, which captured wind gusts in excess of 30 knots from the north/northwest for more than an hour before the capsizing. For example, Martinsburg, West Virginia, recorded 37 knots and 36 knots at 1440 and 1453, respectively. Thus, the meteorologists had the opportunity to monitor and compare the data displays and issue a special marine warning in time to alert the water taxi services operating in Baltimore Harbor. All the Seaport Taxi vessels in operation, including the *Lady D*, were equipped with VHF radios fitted with a NOAA weather alert feature. If Seaport Taxi had received a NOAA alert of a thunderstorm with high winds, the company policy would have called for the vessel captains to tie up.

The Safety Board therefore concludes that meteorological data displayed on the workstation monitors at the NWS Baltimore-Washington forecast office showed that the strong gusty winds and thunderstorm conditions associated with the *Lady D* accident could have been identified by forecasters as early as about 1501, providing opportunity for them to verify conditions and issue a special marine warning more than 20 minutes before the *Lady D* left the dock near Fort McHenry.

Following this accident, the NWS examined the various weather system data available on March 6 at the Baltimore-Washington weather forecast office and critiqued the performance of the meteorologists on duty. The team found that a more aggressive and more efficient approach by forecasters in analyzing the evolving weather conditions could have increased their concern regarding the potential for high winds. This, in turn, could have resulted in timelier and more complete information being provided in forecast and warning services. The assessment team also found that the forecasters did not make optimum use of available NWS equipment. Further, the team recognized that the NWS would benefit from improving the access to mesonet and TDWR system data.

According to NWS officials, the agency's report of findings was made available to weather forecast offices nationwide by means of the NWS website. The NWS will disseminate the training exercises developed by and for the Baltimore-Washington weather forecast office first throughout the eastern region and then to other regions. NWS officials advised Safety Board investigators that they expect their weather forecast offices with marine forecast responsibilities to access and use the training. The Safety Board concludes that the agency-wide actions taken by the NWS to correct its system deficiencies and performance errors are adequate to address the problems that occurred at the Baltimore-Washington weather forecast office.

Seaport Taxi's Weather Policy

Seaport Taxi had a stated weather policy with defined operating parameters, demonstrating that company officials recognized and attempted to mitigate risks to the pontoon-style passenger vessels traversing the harbor in harsh weather. The water taxis could operate in rain; however, the company policy stipulated that vessel masters tie up when they encountered electrical storms, sustained winds over 15 knots or wind gusts over 35 knots, restricted visibility, and other conditions. The company advised its masters about its weather policy in both introductory and annual refresher training classes. During day-to-day operations, the manager at Seaport Taxi's shoreside office would radio information about the weather either at her own initiative or in response to questions from a master in the fleet. In addition, a senior official could advise or order vessel operators to seek a safe haven and tie up their boats if he observed weather conditions that warranted such action. However, recognizing that weather conditions near the Inner Harbor (operating loop 1) and the Canton area (operating loop 2) could differ dramatically, company officials usually left the decision regarding operating in bad weather to the Coast Guard-licensed master. Seaport Taxi vessel masters who encountered difficult wind and wave conditions while operating one of the company's small, single-engine boats on loop 2 could request that a larger boat be assigned to the outer loop route, and the company would arrange a switch.

The *Lady D*'s master told Safety Board investigators that he was aware of the company's operating policy and generally agreed with it. He also told investigators, however, that in the 2 to 3 years that he had worked for Seaport Taxi, he had been caught in 40-knot winds while operating the *Lady D*. He said that he believed that on one occasion, he had been in wind conditions approaching 50-knot gusts; however, he said he had never been in conditions like those on the day of the accident, which did not reach 50 knots. He also stated, and company officials confirmed, that he had operated on loop 2 when conditions were sufficiently bad to warrant his asking that a larger, twin-engine boat be assigned to the outer loop. Thus, when he had operated in the past during wind conditions that exceeded the parameters established by Seaport Taxi, the *Lady D* master had demonstrated that he recognized the limiting weather conditions for that pontoon boat and had alerted the company to make vessel changes for the route.

On the day of the accident, several factors affected the master's decision-making, in particular, his choice to leave the Fort McHenry dock despite evidence of an impending storm. Earlier that day, after arising about 0600, he had monitored the forecast on the Weather Channel and noted that the prediction for that afternoon was sunny skies, with no mention of storms. From the time of his first trip, about 1000, until his last trip to Fort McHenry, the weather conditions he encountered were consistent with the forecast.

When the master docked at Fort McHenry about 1545, he noted the dark clouds north-northwest of Baltimore; however, he considered them distant and not an immediate threat. He had been directed by the Seaport Taxi office manager to pick up passengers at Fort McHenry before it closed at 1600 and return them to Fells Point. He could not embark all those who were waiting at the fort, but he picked up 23 passengers, bringing the total number of persons on board to the maximum load for which the *Lady D* was certificated. As the master prepared to leave, he told the fort coordinator that he would return as soon as possible "to get the last people off," demonstrating that he was somewhat focused on accomplishing his mission.

When the *Lady D* master backed away from the dock about 1554, the weather conditions that he observed met none of Seaport Taxi's criteria that precluded making a transit. The wind began to pick up and light rain began to fall. Because the *Lady D*'s master had operated previously in wind and rain, the weather conditions would not necessarily have affected his decision to proceed to Fells Point.

Human factors research shows that the cognitive effort required to alter a decision once it has been acted upon is more difficult than if the action had not been taken at all.[60] In this case, it would have been more difficult for the master to return after leaving the dock than if he had decided not to leave the dock in the first place. His course of action to proceed to Fells Point was supported by radio communications from company personnel who provided him with operating instructions and information. Immediately after the senior captain radioed the fleet about potential storm conditions and recommended that vessel masters tie up, the Seaport Taxi office manager broadcast that Doppler weather radar indicated that the worst of the storm would miss them. Thus, her transmission probably negated the effect of the senior captain's warning and affected the *Lady D* master's decision to proceed to Fells Point. He told Safety Board investigators that, in the past, the weather reports from the office had generally given the vessel masters adequate warning and enough time to tie up someplace, if necessary.

As noted earlier, the Doppler weather radar image on display at the NWS about the time that the *Lady D* master departed Fort McHenry would have shown a more detailed picture of the impending conditions. However, the timeliness of the broadcast Doppler weather image depends on how long it takes a weather information provider to upload the data feed from the NWS. Based on her description of the Doppler weather radar image on her computer screen, the office manager probably was looking at an earlier Doppler image when she radioed the fleet that the worst of the storm would miss them. The Safety Board concludes that the weather information available to Seaport Taxi at the time of the accident did not accurately reflect the impending storm conditions, which compromised efforts to adhere to safe operating procedures.

Adequacy of Propulsive Power

As discussed earlier in this analysis, the Safety Board evaluated the vessel's propulsion system and found that its mechanical condition was not a factor in this accident. In addition, the Safety Board considered whether the outcome would have been different had the master had additional propulsive power available as he was attempting to maneuver his vessel in the adverse weather.

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[60] C. D Wickens and J. G. Hollands, *Engineering Psychology and Human Performance* (Upper Saddle River, New Jersey: Prentice Hall, 2000).

The master stated that he operated the vessel at 6 knots, well below its maximum operating speed of 12 knots. Vessels in the area in which *Lady D* operated were in a "no-wake zone," and were limited to a speed of 6 knots. Because the vessel was limited to operating at 6 knots and yet had sufficient power to reach 12 knots, the vessel was not underpowered for its operations. In addition, according to design standards for small vessels, a maximum horsepower is recommended to prevent dangerous overpowering of a vessel. In this case, one such standard for pontoon vessels would have limited a vessel of the *Lady D*'s dimensions to about 65 hp.[61] The *Lady D*'s outboard motor was rated at 90 hp. The Safety Board concludes that the propulsive power of the *Lady D* was not a factor in this accident.

Survivability

Several factors affected the survivability of the *Lady D*'s occupants in this accident. The vessel's design, specifically the enclosed deckhouse and the windows, presented barriers to escape. The cabin's canopy precluded donning lifejackets because wearers of the safety devices would not have been able to overcome their buoyancy and would have been trapped in the enclosed cabin. Environmental conditions, in particular the water temperature, increased the potential for serious and fatal injuries. The key factor that contributed positively to the survivability of the *Lady D*'s occupants was the timeliness and effectiveness of the rescue effort.

Construction and Arrangement of the Accident Vessel

During inclement weather, the *Lady D* was one of Seaport Taxi's preferred vessels for operation because the pontoon boat had a fully enclosed deckhouse. However, because of its design, the *Lady D* posed potential egress problems not present on other pontoon vessels in the Seaport Taxi fleet.

The vessel had two doors, which were at opposite ends of the deckhouse. The door at the bow was a horizontal sliding model that moved to the side; the door at the stern was a hinged model that opened outward. The primary means of emergency egress for passengers sitting amidships were the windows along the sides of the *Lady D*. The windows were 42 inches high by 48 inches wide; however, they were combination windows with one 24-inch-wide sliding sash and one 24-inch-wide fixed sash.

Several survivors said that they initially had problems getting out of the capsized vessel. Four passengers seated near the forward or the aft doors conceivably should have been able to readily exit through them. One passenger said, however, that when he tried to open the sliding glass door at the bow as the *Lady D* started to sink, he was unable to move it. The mate later confirmed that he had experienced some difficulty with the front door

[61] American Boat and Yacht Council Standard H-35, "Powering and Load Capacity of Pontoon Boats," July 2003.

when he had helped prepare the vessel for an upcoming Coast Guard inspection. Contrary to the passenger interviewed, the mate recalled that the front door had been easy to open but “very difficult” to close.

Another passenger seated next to the aft door said he believed that he had exited through that door because he swam into the boat propeller as he surfaced. Fortunately, water had already flooded the *Lady D*’s engine, and the propeller was not moving.

A passenger who had been seated midsection on the starboard side said that, in retrospect, exiting through the forward door was an obvious choice; however, in the midst of the emergency, it never occurred to him to try to egress through the forward door. He said that he was able to escape through a window opening.

In this accident, all the fatality victims, who ranged in age from young to middle age and whose physical conditions varied, were seated amidships. The closest means of egress for those passengers were the windows, which were closed to protect passengers from wind and rain during the voyage.

Some passengers stated that they were able to slide the windows open and exit. One survivor said that after the vessel overturned, he kicked at the windows and felt one give way. Several passengers said that they had problems finding an open window because the water was so murky. Others said that with the boat upside down, they realized they would have to swim downward to find a window exit. One woman stated, “I kicked to go down, and I started feeling…I pushed a window and it seemed to just, just to float away. I don’t think…it was attached anymore. So, I could…just go out of that window.”

The Safety Board therefore concludes that in the panic situation that ensued after the *Lady D* capsized, the vessel’s normal means of egress from the deckhouse, including the differently designed doors and the slider windows, posed evacuation problems for the vessel’s occupants.

Safety Briefing

Federal regulations at 46 CFR 185.506 stipulate that a vessel master must ensure that before getting underway, suitable public announcements are made informing all passengers of the location of emergency exits, ring buoys, instructional placards, and lifejackets. In addition, passengers must be informed about how to don a lifejacket.

Seaport Taxi had installed a placard indicating how to don a lifejacket inside the *Lady D*’s deckhouse and required that operating crews deliver a safety briefing. The Safety Board received conflicting accounts about whether a safety briefing was performed at the outset of the accident voyage. The master and the mate both told investigators that a safety announcement advising passengers about the location of lifejackets was performed. However, most of the *Lady D*’s survivors either could not recall receiving a safety briefing on board the *Lady D* or stated that the crew did not conduct one. Almost all survivors said that they had received a safety briefing on other Seaport Taxi vessels at Harbor Place for the trip to Fells Point.

From postaccident interviews, the Safety Board determined that passengers might have benefited from receiving a safety briefing specific to the *Lady D*'s characteristics much like the type of briefing provided to passengers on a particular model of aircraft. The door at the bow and the door at the stern opened differently. For passengers sitting amidships, the windows were the logical source of egress; however, each window was a combination style with one fixed sash and one sliding sash. In this accident, several occupants of the deckhouse escaped when some of the windows ultimately gave way, either from passengers kicking on them or from the water exerting pressure against them, or both.

The passengers also should have been advised about whether and when it was appropriate to don a lifejacket. This subject is discussed in greater detail in the following section.

A verbal safety briefing serves several purposes: It refreshes the crew's understanding of emergency procedures, informs passengers, and provides them with the opportunity to ask questions if they do not understand recommended emergency procedures. Conditions are generally so chaotic during an emergency that individuals need to be able to identify an appropriate action and respond quickly. The Safety Board concludes that the currently required safety briefing on emergency procedures that includes a discussion of lifejacket stowage/donning and egress capabilities would enhance small passenger vessel safety.

Lifejacket Use in Enclosed Deckhouses

Because of the suddenness of the vessel's capsizing and its rapid flooding, passengers had little opportunity to retrieve and don lifejackets, which, in this case, probably contributed to survivability. Donning a lifejacket inside a rapidly flooding enclosed deckhouse could have resulted in the buoyant safety device carrying a wearer upward when most people had to swim downward to escape. Wearing a lifejacket inside the overturned *Lady D* would have impeded mobility, made exiting through the windows difficult if not impossible for several passengers, and delayed egress. Several young children were on board the *Lady D*. If a parent had taken time to find a child-size lifejacket and put it on a youngster, both the parent and the child might not have escaped from the vessel. Following this accident, several passengers with past boating experience told investigators that they realized wearing a lifejacket inside an enclosed deckhouse was not recommended when the vessel threatened to capsize. No passenger on the *Lady D* donned a lifejacket before the vessel turned over.

Much research has shown the benefits of wearing lifejackets, particularly in waters as cold as the Patapsco River on the day of the accident (44° F), and normally the Safety Board is a strong proponent of lifejacket use in hazardous conditions and marine emergencies. However, in the case of the *Lady D* capsizing, passengers should have only retrieved and held the lifejackets in preparation for possible evacuation while the boat rocked in the wind. When the vessel overturned, they could have pushed a lifejacket out a window or door to serve as a flotation device after they escaped the boat and swam to the surface.

In this case, the pontoon vessel itself became the best flotation device for vessel occupants who found their way out of the deckhouse. The survivors either climbed on the overturned boat or pulled others in getting on top of it. Two survivors were still in the water, holding onto the boat, when rescuers arrived. Two passengers died as a result of being trapped in the vessel. Because the cabin ultimately tore free of the deck, it is not known whether the remaining three fatality victims died in the vessel or were able to exit the vessel but not reach the water's surface. The Safety Board therefore concludes that donning lifejackets in the *Lady D*'s enclosed deckhouse before the capsizing could have resulted in additional fatalities.

Response Effort

The response to this accident was rapid and effective. People at shoreside installations, including personnel at the Naval Reserve Center Baltimore and a BCFD marine unit member at the fireboat station, witnessed the capsizing and immediately called 911, notifying the dispatcher at the emergency communications center of the accident within seconds of the *Lady D*'s overturning. The calls to the consolidated communications system enabled the BCFD to initiate a response from all necessary City public safety agencies. More than 40 rescue and medical personnel and various marine and shore-based assets were dispatched by 1603, or within about 5 minutes of the water taxi's capsizing at 1558. Thus, timely efforts by witnesses to notify the 911 dispatcher contributed to an effective response by City safety agencies.

The Navy reservists also contributed to the prompt rescue of the accident victims. The Reserve center pier was about 1/3 nm from the position of the capsized water taxi. After witnessing the *Lady D* overturn, the reservists quickly put together a crew and launched an LCM-8. Within 8 minutes of the capsizing (1606), they had arrived at the accident site and begun transferring survivors to their vessel. Upon learning that passengers were still trapped inside the *Lady D*'s cabin, the LCM-8 operator lowered the ramp on the LCM-8 and used it as a lever to lift one side of the pontoon vessel, which freed at least three passengers. The quick thinking of the LCM-8 operator, therefore, probably saved the lives of some passengers.

The BCFD's fire/rescue boat and the police department's vessel arrived at the site shortly after the LCM-8. The crews of the three vessels communicated and worked well together. As a result, several passengers needing immediate medical attention were transferred to either the BCFD rescue boats or the BCPD vessel, all of which carried EMTs who could provide life-saving treatment while the passengers were transported to ambulances waiting on shore. Because of the combined response efforts of marine and shore-based personnel with the Navy Reserve, the BCFD, and the BCPD, 22 occupants of the accident vessel were rescued from the water and transported to area hospitals within an hour of the capsizing.

While the volunteer and the City responders were working at the accident site, Coast Guard watchstanders monitoring VHF channel 16 overheard radio traffic about the capsizing. Immediately thereafter, about 1617, Seaport Taxi notified the Coast Guard of the accident, as required by 46 CFR 4.04, after water taxi officials were able to confirm that one of their vessels had overturned. Company officers had learned of the accident only after they did not receive a response to their radio and cell phone calls to the *Lady D* and took another vessel out toward Fort McHenry to determine why.

Coast Guard officers sounded the SAR alarm and contacted Baltimore's emergency communications center. The BCFD battalion chief, as incident commander, effectively briefed Coast Guard personnel about the emergency, advising them that four rescue vessels were already on scene. The Coast Guard ordered a crew muster for the dispatch of three utility boats and one search helicopter to assist, and the first vessel was underway by 1625. By the time the first utility boat arrived on scene at 1637, most of the *Lady D*'s occupants had already been recovered. The incident commander then effectively merged the responding Coast Guard assets into a multiagency SAR operation to search for the three missing passengers.

The Safety Board concludes that the rapid response effort by personnel from Naval Reserve Center Baltimore to the *Lady D*'s capsizing probably resulted in fewer lives being lost. Moreover, the actions of all City and first responders, including the fire department, the police, the emergency medical technicians, and the Coast Guard, were timely and effective.

Conclusions

Findings

1. Sleep deprivation, alcohol, drugs, and physical impairments were not factors in this accident.

2. The mechanical condition of the *Lady D*'s propulsion and steering systems was not a factor in this accident.

3. The propulsive power of the *Lady D* was not a factor in this accident.

4. Examination of the *Lady D*'s hull showed no evidence of preaccident damage.

5. The load for which the pontoon vessel *Lady D* was certificated was based on a monohull simplified stability proof test on the *Fells Point Princess*, which was not appropriate for pontoon vessels.

6. As a result of inappropriate sister vessel status to the *Fells Point Princess* being granted to the *Raven*, the *Lady D*, and the *Misty Harbor II*, all four pontoon boats had serious deficiencies in stability as a result of the inappropriate stability test used to determine the number of persons allowed on all the vessels. Although it was the *Lady D* that was involved in this accident, the potential risk of a capsize event was substantially the same for all four vessels during their years of operation.

7. The combination of the use of an out-of-date average weight standard for occupants of small passenger vessels and the excessive number of persons permitted in the *Lady D*'s original certification resulted in the pontoon boat carrying a load that reduced its reserve buoyancy and compromised its stability characteristics, which made it more susceptible to capsizing on the day of the accident.

8. The *Lady D* capsized as a result of the combined effects of the excessive load it carried and the wind and wave conditions experienced at the time of the accident.

9. Masters need a simple and ready means such as a mark on the hull to determine whether their vessels are overloaded and potentially unsafe.

10. Existing Coast Guard intact stability standards for pontoon passenger vessels (the pontoon simplified stability test in Subchapter T, "Small Passenger Vessels," and/or the alternative criteria in Subchapter S, "Subdivision and Stability") do not adequately account for the dynamic loading from wind and waves on a pontoon vessel operating on an unrestricted protected route.

11. A Coast Guard endorsement on a vessel's certificate of inspection restricting a pontoon passenger vessel to limiting weather conditions would provide definitive operational guidance to a vessel's operator.

12. Meteorological data displayed on the workstation monitors at the National Weather Service Baltimore-Washington forecast office showed that the strong gusty winds and thunderstorm conditions associated with the *Lady D* accident could have been identified by forecasters as early as 1501, providing opportunity for them to verify conditions and issue a special marine warning more than 20 minutes before the *Lady D* left the dock near Fort McHenry.

13. The agency-wide actions taken by the National Weather Service to correct its system deficiencies and performance errors are adequate to address the problems that occurred at the Baltimore-Washington weather forecast office.

14. The weather information available to Seaport Taxi at the time of the accident did not accurately reflect the impending storm conditions, which compromised efforts to adhere to safe operating procedures.

15. In the panic situation that ensued after the *Lady D* capsized, the vessel's normal means of egress from the deckhouse, including the differently designed doors and the slider windows, posed evacuation problems for the vessel's occupants.

16. The currently required safety briefing on emergency procedures that includes a discussion of lifejacket stowage/donning and egress capabilities would enhance small passenger vessel safety.

17. Donning lifejackets in the *Lady D*'s enclosed deckhouse before the capsizing could have resulted in additional fatalities.

18. The rapid response effort by personnel from Naval Reserve Center Baltimore to the *Lady D*'s capsizing probably resulted in fewer lives being lost. Moreover, the actions of all other City and first responders, including the fire department, the police, the emergency medical technicians, and the U.S. Coast Guard, were timely and effective.

Probable Cause

The National Transportation Safety Board determines that the probable cause of the capsizing of the pontoon-style small passenger vessel *Lady D* was its lack of intact stability, which was insufficient to withstand the strong winds and waves that the boat encountered. The lack of intact stability was caused by overloading, which resulted from a combination of the following:

- The *Lady D* was erroneously granted sister status by the U.S. Coast Guard to a pontoon vessel with different design characteristics;
- The Coast Guard certificated the *Lady D* to carry too many people as a result of an inappropriate stability test on the vessel to which it was granted sister status; and
- The Coast Guard's regulatory stability test standards on which the *Lady D*'s passenger allowance was based use an out-of-date average passenger weight.

Recommendations

As a result of its investigation of the *Lady D* accident, the National Transportation Safety Board makes the following recommendations.

New Recommendations

To the U.S. Coast Guard:

> Revise regulations to require that passenger capacity for domestic passenger vessels be calculated based on a statistically representative average passenger weight standard that is periodically updated. (M-06-5)
>
> Identify a method for determining the maximum safe load condition of a small passenger vessel at the time of loading, such as a mark on the side of the hull, and require that the vessel owners implement that method. (M-06-6)
>
> Revise the stability criteria for small passenger pontoon vessels for all passenger loading conditions to minimize the potential for capsizing in wind and waves. (M-06-7)
>
> Until such time as you revise the passenger weight standard as requested in Safety Recommendation M-06-5 and the stability criteria used to evaluate small passenger pontoon vessel safety as requested in Safety Recommendation M-06-7, develop interim pontoon passenger vessel stability guidance based on static and dynamic intact stability considerations. (M-06-8)
>
> Establish limiting environmental conditions such as weather in which pontoon vessels may safely operate, and list those limiting conditions on the vessel's certificate of inspection. (M-06-9)

Previously Issued Recommendation Classified in This Report

> M-04-4
>
> Revise your guidance to Officers in Charge, Marine Inspection, to determine the maximum occupant capacity of small passenger pontoon vessels either (1) by dividing the vessel's simplified stability proof test weight by the per-person weight allowance for an average adult stipulated in Federal Aviation Administration Advisory Circular 120-27D (174 pounds per person, assuming summer clothing and a 50-50 gender mix), or (2) by restricting (at the time of loading) the actual cumulative weight of passengers and crew to the vessel's simplified stability proof test weight.

Safety Recommendation M-04-4 (previously classified "Open—Acceptable Response") is classified "Closed—Superseded" by Safety Recommendation M-06-5 as discussed in the "Passenger Weight Criteria for Stability Assessments" section of this report.

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

MARK V. ROSENKER
Acting Chairman

DEBORAH A. P. HERSMAN
Member

ELLEN ENGLEMAN CONNERS
Member

KATHRYN O'LEARY HIGGINS
Member

Adopted: March 7, 2006

Appendix A

Investigation

The National Transportation Safety Board learned of this accident from media accounts about 1700 on March 6, 2004, and launched a four-person investigative team consisting of an investigator-in-charge and specialists in human performance, operations, and survival factors. The team was joined by the then Chairman, her assistant, and representatives from the Safety Board's offices of Public Affairs and Transportation Disaster Assistance. The investigative team conducted on-scene interviews between March 6 and March 14. On March 10, 2004, a vehicle performance specialist joined the investigative team.

On May 11, 2004, the Safety Board assisted in the survey of the *Lady D* wreckage. Members of the team subsequently conducted follow-up interviews on October 26, 2004.

The Safety Board investigated the accident under the authority of the Independent Safety Board Act of 1974, according to the Board's rules. The parties to the investigation were the U.S. Coast Guard, the Living Classrooms Foundation (the owner of the *Lady D*), the National Weather Service, the City of Baltimore Fire Department, and Susquehanna Santee Boatworks, Inc. (the holder of construction records on the *Lady D*).

Appendix B

Intact Stability Study of *Lady D*

Conducted by Alion Science and Technology, JJMA Maritime Sector

ALION
SCIENCE AND TECHNOLOGY

DELIVERABLES 1 & 2
MV LADY D INTACT STABILITY WITH WIND

Purchase Order No. NTSBF060005

December 15, 2005

Prepared for:

National Transportation Safety Board
Office of Marine Safety

Prepared by:

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ALION
SCIENCE AND TECHNOLOGY

1. INTRODUCTION

This report presents the results of Task 1 and Task 2 of NTSB Purchase Order NTSBF060005. It combines Deliverables 1 and 2 into a single report since the two tasks are very closely related. This report summarizes the basics of intact stability as they apply to pontoon vessels. It also describes the static intact stability of the MV LADY D that was analyzed for three loading cases and three wind speeds.

2. ASSESSING INTACT STABILITY OF VESSELS

Intact stability is the naval architect's term that describes how a vessel that is intact, or undamaged, responds when heeled (tipped) over. How a vessel responds when it is damaged is called damaged stability and that subject is outside the scope of this report. There are a number of forces that act on vessels that can cause the vessel to heel over. Some of the common heeling forces are: wind, waves, and the movement of passengers or cargo. Heeling forces are counteracted by the buoyancy of the hull of the vessel. As a vessel is heeled over the location of the buoyant forces shifts which produces a righting moment. If the righting moment is equal to the heeling moment, the vessel is in equilibrium and will remain in that position until the equilibrium is disturbed. If the heeling moment is greater the righting moment the vessel will continue to heel over and will turn completely over, or capsize.

The shape of the vessel's hull determines its buoyancy and how much righting energy is produced. In the case of a pontoon boat, see Figure 1, the two pontoons both produce buoyancy that counteracts heeling forces. The force of buoyancy of the two hulls can be turned into a single, (combined) buoyancy force. The distance measured perpendicular to the line of the combined buoyancy and the line of the weight of the boat is the "righting arm" of the boat. The greater the righting arm of the vessel, the more heeling force the vessel can resist.

Righting arm changes as a vessel is heeled over. When a vessel is floating level, with a heel angle of 0 degrees, the righting arm is zero because the force of buoyancy and weight are aligned. As a vessel is heeled over the center of buoyancy shifts outboard, creating a "righting arm" that tends to push the boat back to the upright position. As the vessel heels over further, the righting arm increases, see Figure 2, until it reaches a maximum. This point is called the vessel's maximum righting arm. Beyond the point of maximum righting arm, the righting arm decreases until it reaches zero, which is called the point of

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vanishing stability. The distance from 0 degrees heel and the point of vanishing stability is called the vessel's "range of stability". At heel angles beyond the point of vanishing stability the vessel's center of gravity has shifted further outboard than the center of buoyancy and so the righting arm becomes negative, creating a moment that forces the vessel to heel more, eventually leading to capsize.

The area under the righting arm curve is a measure of the vessel's righting energy. The righting energy is important because this is the energy that is available to counteract forces that would heel the vessel over. This righting energy resists environmental forces that affect the vessel such as wind and waves. The vessel must have sufficient righting energy to counteract the environmental forces that the vessel is expected to encounter during its lifetime.

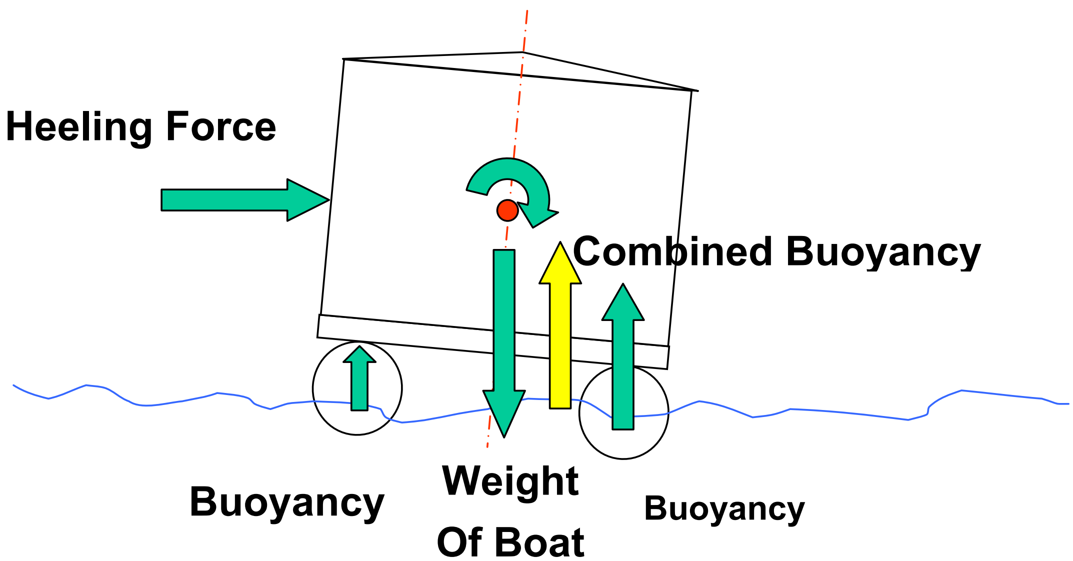

Figure 1 Intact Stability of a Pontoon Boat

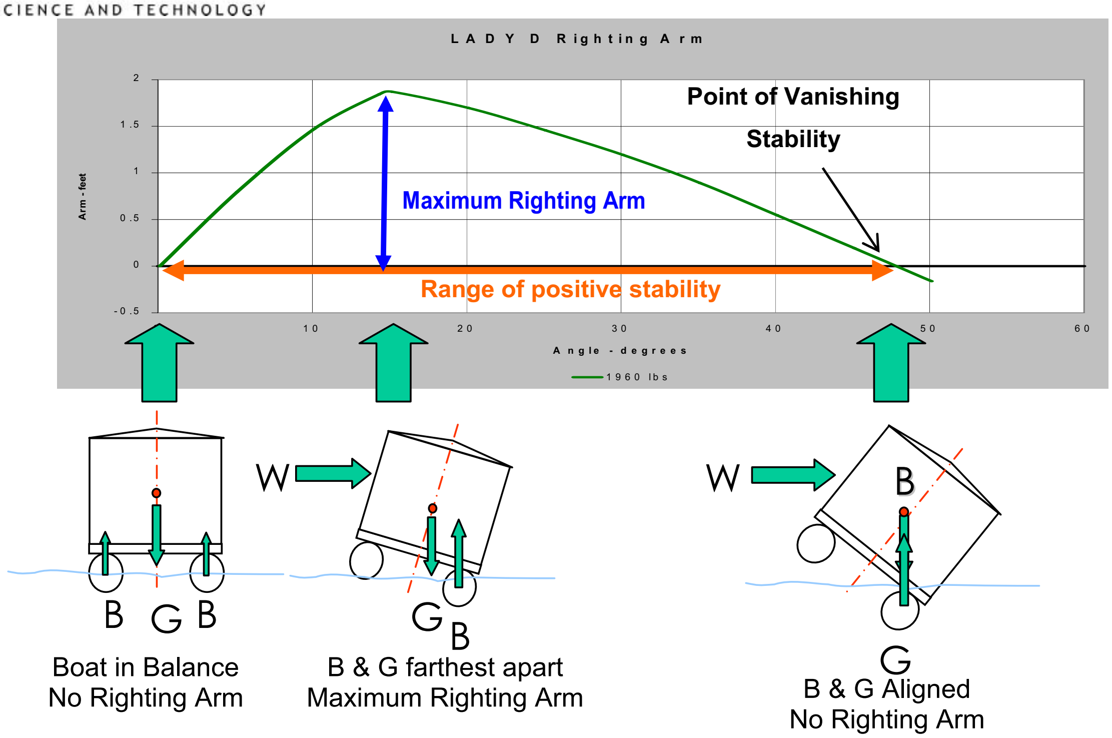

Figure 2 Righting Arm over a Range of Heeling Angles

The calculation of righting arm for any vessel is usually performed using computer programs. The hull form of the vessel is entered into the program for use in calculating a number of different properties of the vessel. These properties are referred to as the vessel's "hydrostatics". To calculate righting arm for the vessel, the program systematically changes the angle of heel of the hull. As the vessel is heeled, the program calculates the shift in the hull's center of buoyancy. The program adjusts the mean of the draft of the hull to keep the volume of water displaced by the hull (buoyancy) equal to the vessel's weight. Once the position of the hull's center of buoyancy (B) is calculated, the perpendicular distance from the vessel's center of gravity (G) to a line extending vertically from the center of buoyancy is measured. This is the vessel's righting arm, which naval architects refer to as GZ (see Figure 3). The intersection of the vertical line from the center of buoyancy (B) to the vessel's center line is called the ship's metacenter (M). The distance from the ship's center of gravity (G) to the metacenter (M) is referred to by naval architects as the vessel's metacentric height, also known as GM.

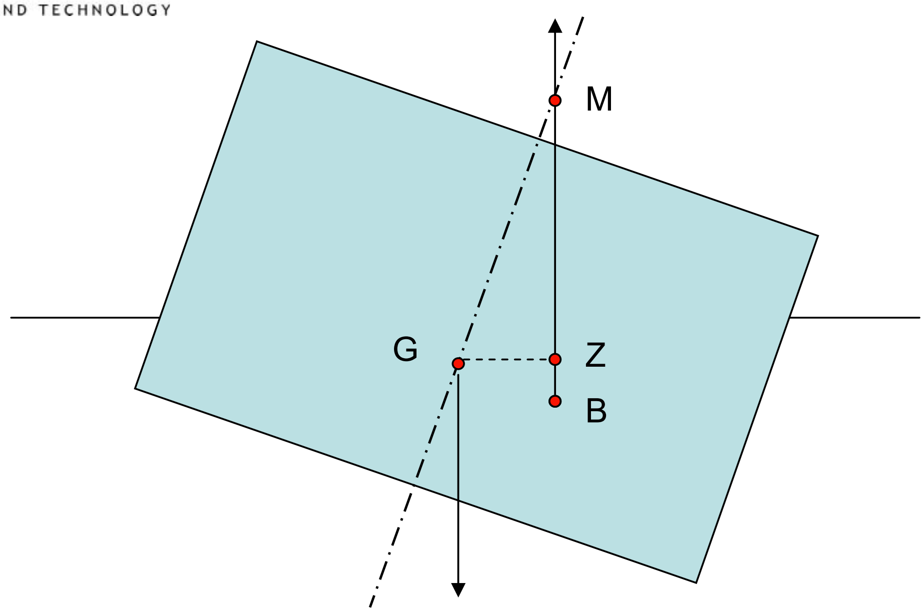

Figure 3 Calculation of Righting Arm

A vessel's GM is frequently used by naval architects as a measure of a vessel's stability. It is a good indication of the vessel's stability at small angles of heel ("initial stability"). The vessel's initial GM is the slope of the righting arm curve at zero degrees of heel angle (Figure 4). If the initial GM is high, the righting arm curve increases rapidly giving large righting arms for only small angles of heel. If initial GM is low, then the righting arm curve goes up slowly allowing the vessel to heel over farther. Vessels with positive GM when they are heeled to one side will resist the force and return themselves to a central upright position when the heeling force is removed. A vessel with negative GM is unstable and any upsetting force will cause the vessel to move away from its initial position. Vessels with two hulls, also called catamarans, such as a pontoon vessel, tend to have a very high initial GM, unless their center of gravity is very high or they are very heavily loaded.

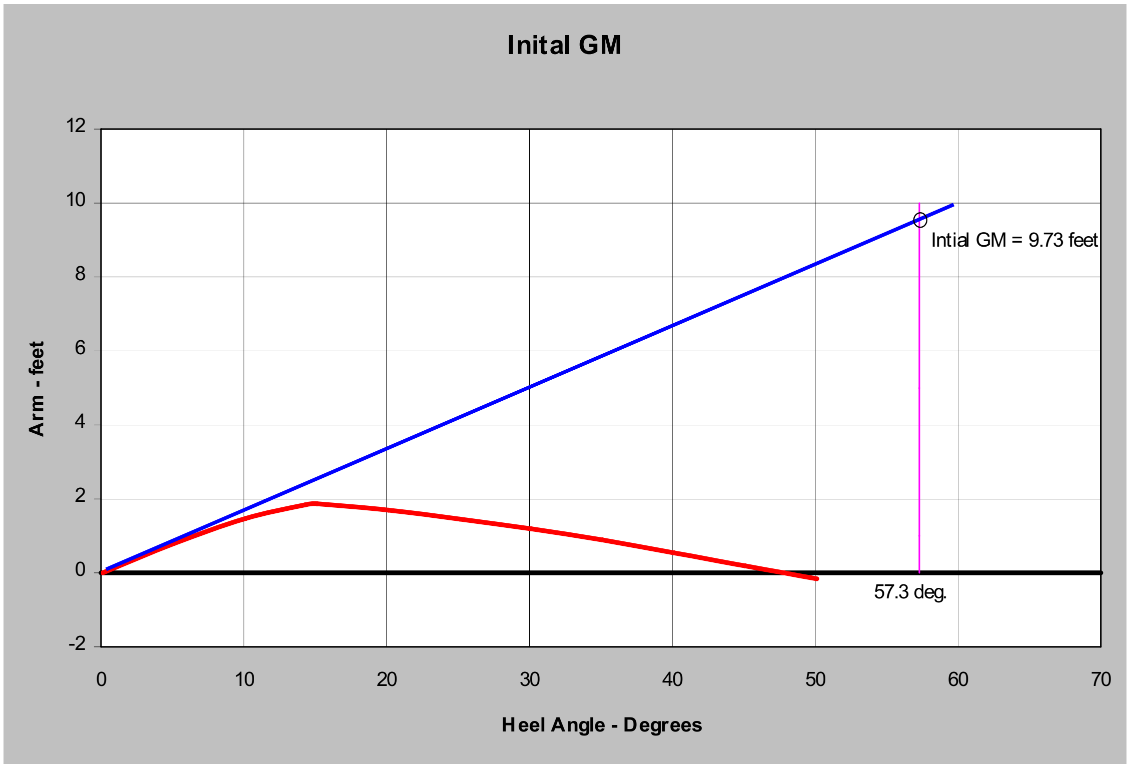

Figure 4 Initial GM

3. WIND HEELING FORCES

As mentioned in the last section, there are a number of common heeling forces that act on vessels: wind, waves, and passenger/cargo loads. Wind forces can be a major influence on any vessel. The major factors in calculating these forces are the area of the vessel that is exposed to the wind, also called sail area, and the wind speed. As a vessel heels over the sail area decreases so the heeling forces decrease. A sample graph showing wind heeling forces versus heeling angle is shown in Figure 5.

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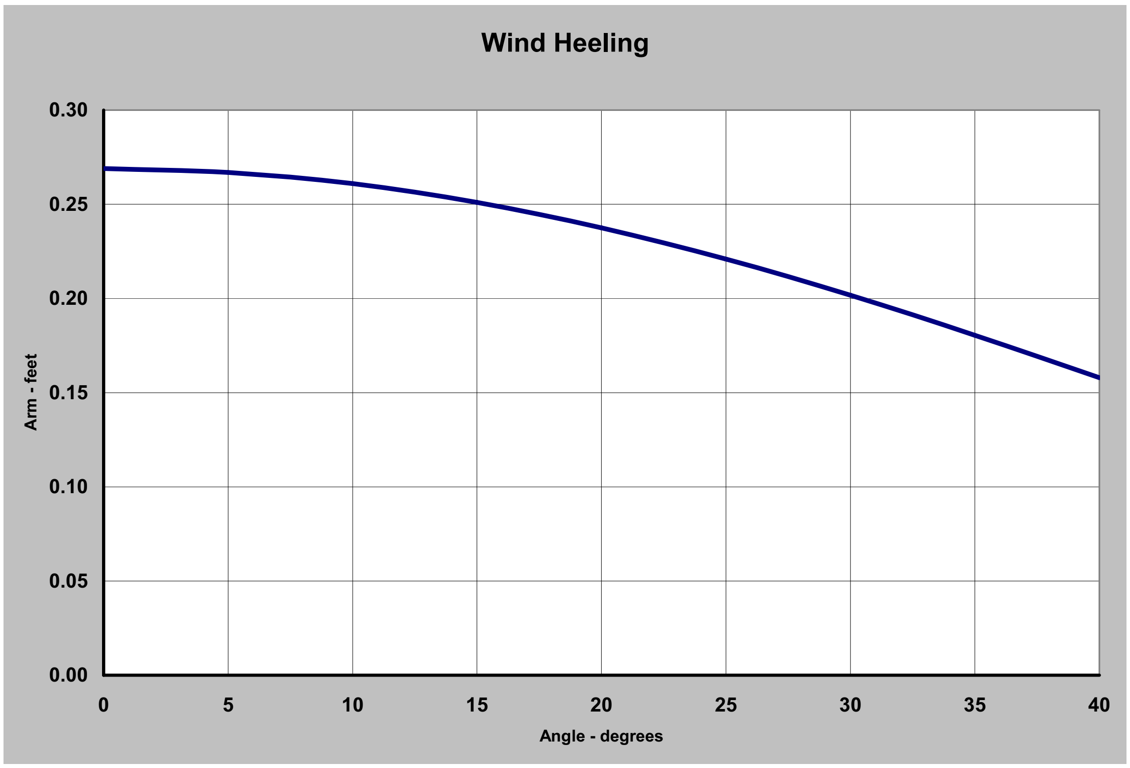

Figure 5 Winding Heeling Forces versus Heel Angle

Wind heeling arm curves are usually plotted on the same graph as a vessel's righting arm curve (Figure 6). The righting arm and wind heeling curves show important information about a vessel's intact stability in wind. The first intersection between the righting arm curve and the wind heeling arm curve is the equilibrium point. The angle of this intersection is how far the vessel would be heeled by a steady wind. If the wind heeling arm exceeds the vessel's righting arm the vessel will capsize. The second intersection point between the two curves is the point of vanishing stability in for the vessel at that wind speed. A steady wind heels a vessel over and reduces the amount of righting energy that is available to counteract environmental variables such as wind gusts or waves. The area between the two curves is called by naval architects the vessel's "residual righting energy". It is the vessel's reserve of righting energy that is available to counteract dynamic heeling forces. Stability criteria for ships that use the concept of righting energy usually do not consider the full area under the righting arm curve, but rather use only a portion of it, such as the area to the angle of maximum righting arm, the angle of downflooding, or a specified angle in degrees. This approach is conservative because it builds in an unspecified factor of safety. The simplified stability test of 46 CFR 178.349 (PSST), does not explicitly require the calculation of wind heeling forces, but environmental factors are implicitly taken into account as part of the criteria used in the test.

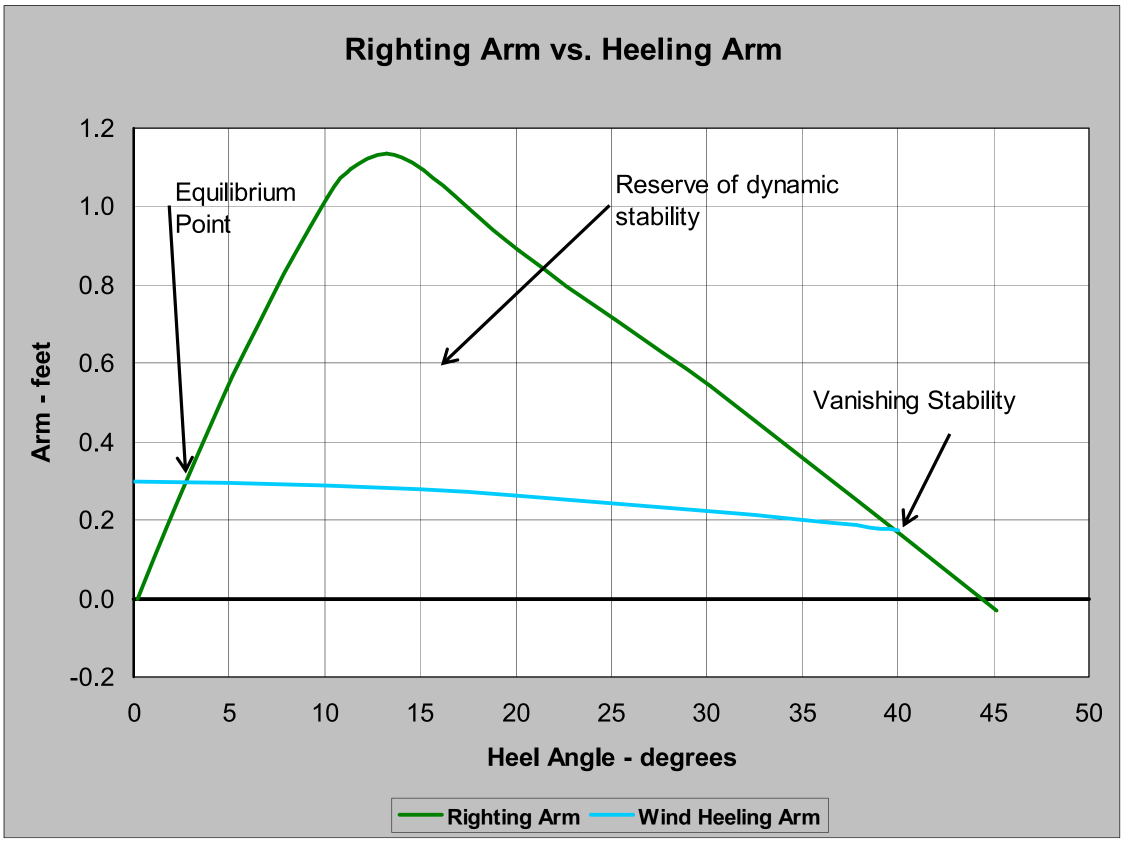

Figure 6 Righting Arm versus Wind Heeling Arm

4. INTACT STABILITY OF THE MV LADY D IN 3 LOADING CONDITIONS

The weight of the passengers carried by the MV LADY D has a significant effect on the vessel's intact stability. Three load cases were examined which varied by the number of people on the vessel and their average weight. The first case examined was for 14 persons weighing an average of 140 pounds each (1960 pounds total). This case represents the maximum safe load condition allowed for the MV LADY D in accordance with the simplified stability test in 46 CFR 178.340. The second load case examined was for 25 persons each weighing 140 pounds (3500 pounds total). This case represents the load that

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was allowed under the USCG Certificate of Inspection for the LADY D. The third loading case is the vessel loaded with 25 persons weighing an average of 168.4 pounds (4210 pounds total). This case represents how the LADY D was actually loaded at the time of the accident. For each of these three load cases curves of righting arm versus heel angle were developed. All three curves are shown plotted on one graph in Figure 7. The top, solid curve is for the first loading case of 1960 pounds. The middle, line with two dashes curve is for the second case with 3500 pound load. The bottom, dashed curve, is for the LADY D as loaded on the day of the accident (4120 pounds).

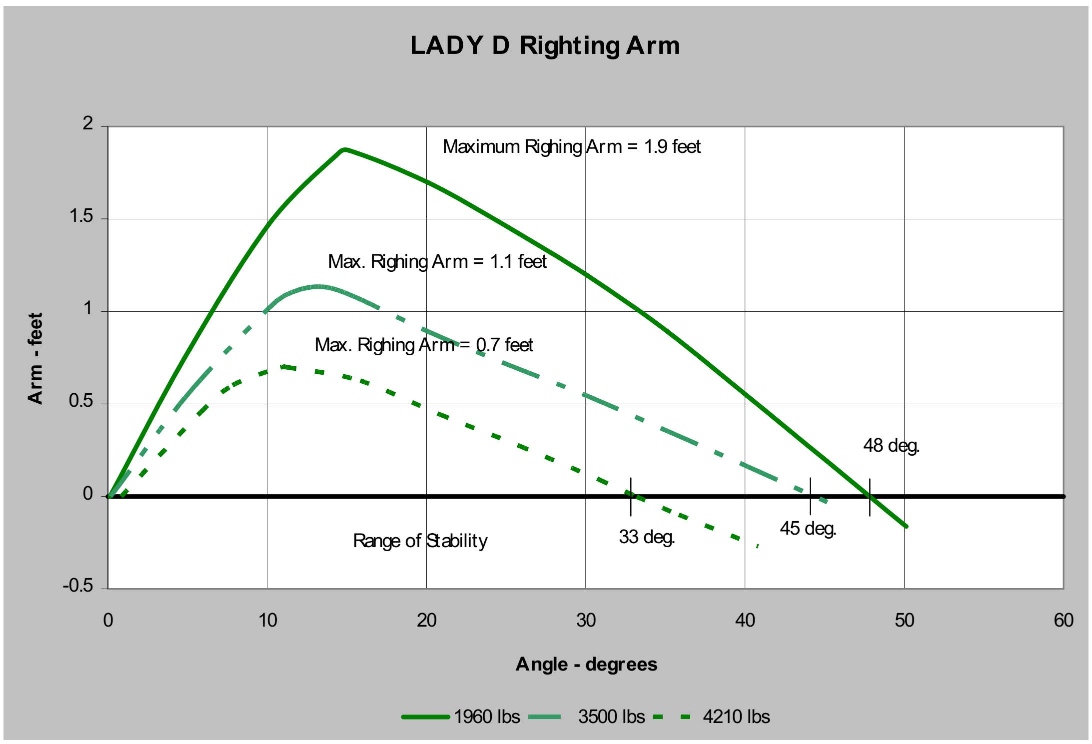

Figure 7 Righting Arm Curves for Three Load Cases

This figure shows how increasing the load carried by the vessel significantly decreases the maximum righting arm of the vessel and the range of stability. The maximum righting arm for the vessel in the first load case is 1.9 feet and it has a range of stability of about 48 degrees. In the second load case the maximum righting arm is 1.1 feet and the range of stability is about 45 degrees. In the third load case the maximum righting arm is only 0.7 feet and the vessel has a range of stability of only 33 degrees. On the day of the accident, once the LADY D reached a 33 degree angle of heel, there was no righting arm left to bring the vessel back to an even keel so she would keep tipping until she was completely turned over.

The passenger load on the LADY D on the day of the accident had a major negative effect on the vessel's intact stability. The weight of the persons onboard the vessel increased her draft which reduced the reserve buoyancy of the pontoons. The reserve buoyancy of the pontoons, especially of the far side pontoon, is what produces the righting force that counteracts environmental forces that may heel the vessel farther over. Therefore the loss of the reserve buoyancy reduced the ability of the LADY D to resist environmental factors, such as wind and waves, on the day of the accident.

5. WIND HEELING FORCES ON THE DAY OF THE ACCIDENT

The ability of the LADY D, as loaded on the day of the accident, to resist wind heeling forces was examined for three wind speeds acting on the vessel's beam. The three wind speeds examined were 30, 40, and 50 knots. Wind heeling curves were generated for each of these wind speeds and they were plotted against the vessel's righting arm, as shown in Figure 8. The figure shows that as the wind speed increases the vessel losses "residual righting energy". In the 50-knot wind case, the wind heeling arm exceeds the vessels righting arm which would result in the vessel's capsizing. A steady state wind speed of 40-knots alone is not sufficient to capsize the vessel outright, but there is little "residual righting energy" remaining to counteract any other dynamic heeling forces such as wind gusts and waves.

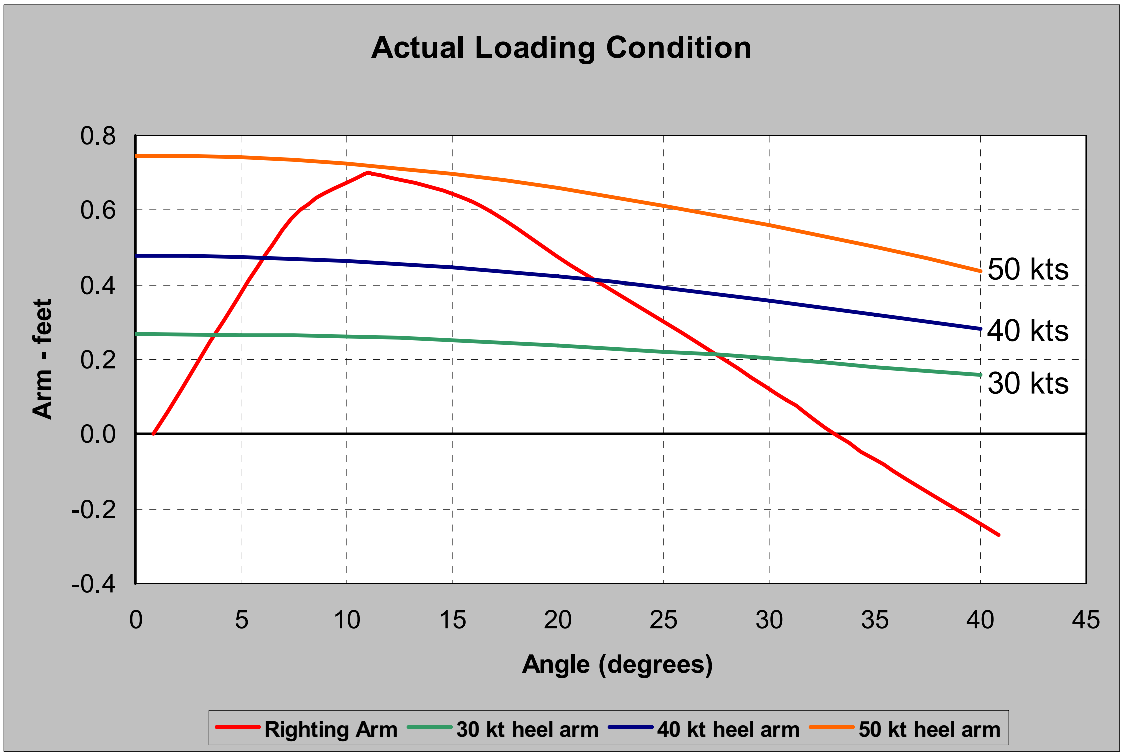

Figure 8 Righting Arm versus Wind Heeling Arm for 3 Wind Speeds

The impact of a 40-knot steady wind on the intact stability of the LADY D as loaded on the day of the accident is shown in Figure 9. This figure shows the "residual righting arm" for the vessel, which is the difference between the righting arm for the vessel and the wind heeling arm. The figure shows that a steady 40-knot wind would heel the vessel over to a 6.1 degree angle in calm water. Figure 10 is a sketch of the vessel looking at the bow in the heeled condition. The pontoon on the opposite side from the wind is deeply submerged and has little reserve buoyancy left to counteract any additional heeling forces. At an angle of slightly less than 22 degrees of heel, the vessel has no more righting energy and there is nothing to prevent the vessel from capsizing. Any additional external force (such as a gust of wind or a wave hitting the boat), a rapid maneuver by the boat's captain, or a shift in the boat's center of gravity due to passenger movements would be enough to capsize the vessel. At this wind speed there is very little margin remaining in the vessel's intact stability to counteract any additional heeling forces.

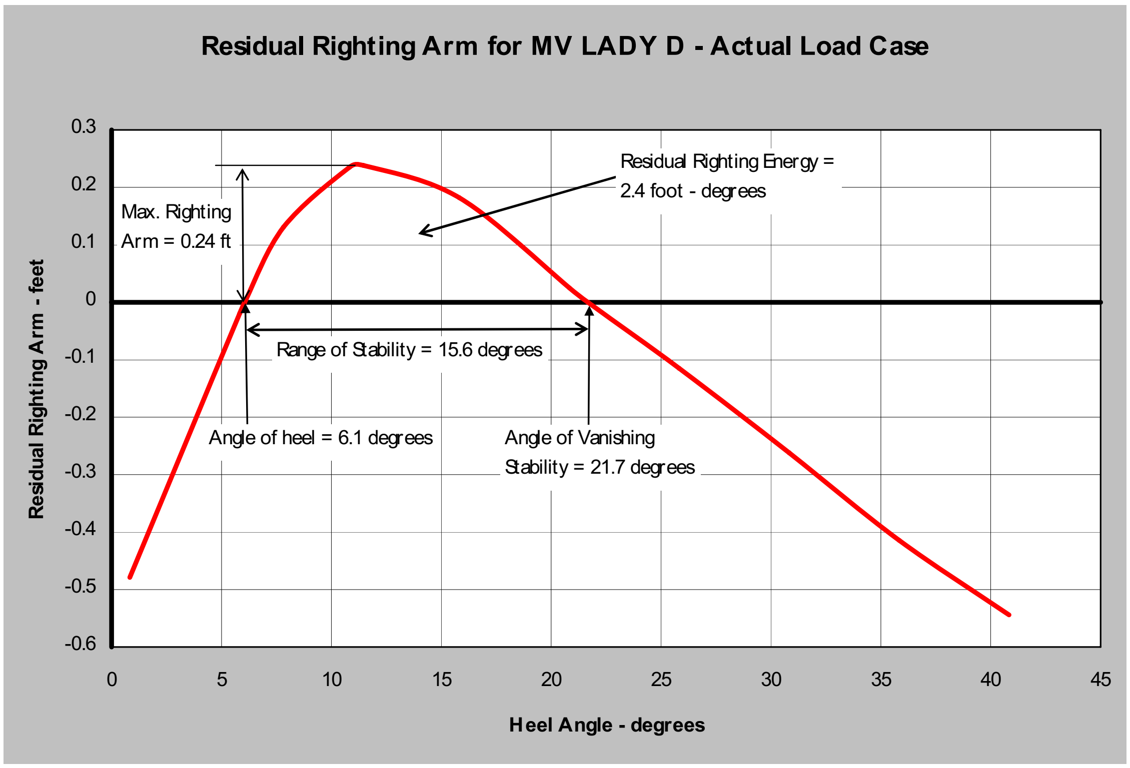

Figure 9 Residual Righting Arm for LADY D in a 40-Knot Wind

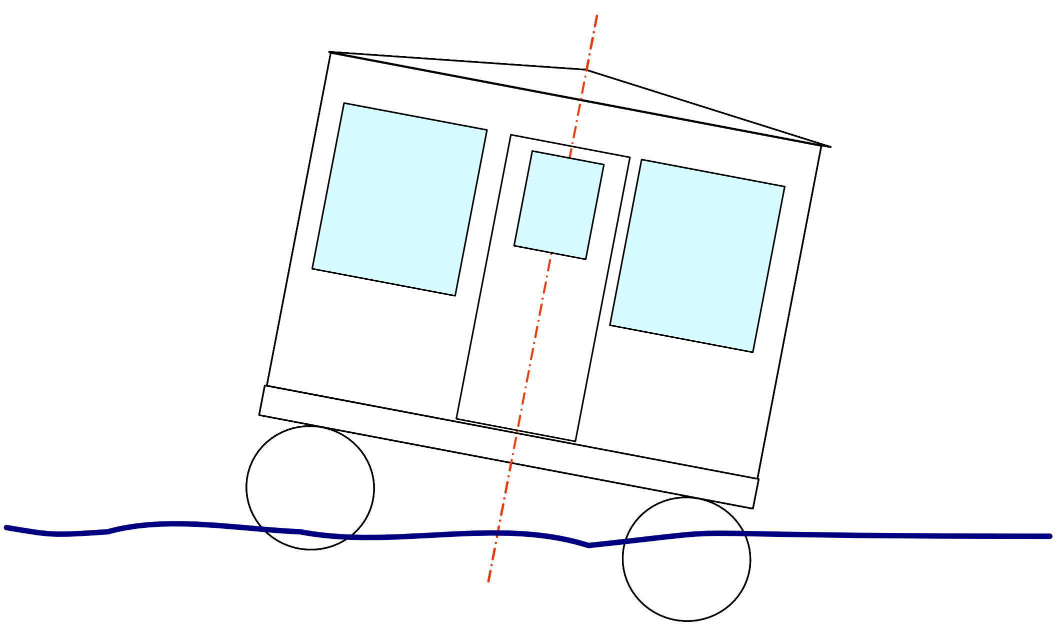

Figure 10 Sketch of LADY D in the Heeled Condition

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DELIVERABLE 3
TABLE OF WIND HEEL VERSUS RIGHTING ENERGY
FOR THREE LOADING CONDITIONS
FOR MV LADY D

Purchase Order No. NTSBF060005

December 8, 2005

Prepared for:

National Transportation Safety Board
Office of Marine Safety

Prepared by:

Alion Science and Technology
JJMA Maritime Sector
4300 King Street, Suite 400
Alexandria, VA 22302

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P.O. NTSBF060005
DELIVERABLES 1 & 2

Loading Case	Total Load - pounds	Residual Righting Energy at Different Wind Speeds – foot-degrees		
		30 Knots	40 Knots	50 Knots
14 people at 140 lbs each	1960	37.32	27.79	16.70
25 people at 140 lbs each	3500	16.95	10.27	3.68
Actual Condition	4210	6.27	2.40	None

In the actual loading condition at a 50 knot wind speed, the vessel would capsize as the heeling energy is greater than the righting energy.

Appendix C

U.S. Coast Guard Policy Letter 04-10, Evaluation of Stability and Subdivision Requirements for Small Passenger Vessels Inspected Under 46 CFR Subchapter T

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

Commandant
United States Coast Guard

2100 Second Street, S.W.
Washington, DC 20593-0001
Staff Symbol: G-MOC-1
Phone: (202) 267-2735
Fax: (202) 267-4394

16711/46 CFR 178
MOC Policy Letter 04-10

OCT 7 2004

From: M. B. Karr, CAPT
COMDT (G-MOC)

M. B. Karr

To: Distribution

Subj: EVALUATION OF STABILITY & SUBDIVISION REQUIREMENTS FOR SMALL PASSENGER VESSELS INSPECTED UNDER 46 CFR SUBCHAPTER T

Ref: (a) 46 CFR 178.330
(b) 46 CFR 178.340
(c) COMDTINST M16000.9, Marine Safety Manual, Volume IV, Chapter 6

1. Purpose: This memorandum provides updated guidance to Officers in Charge, Marine Inspection (OCMI) for determining the applicability of simplified stability proof tests required by reference (a). In particular we limit types of vessels that may use the simplified stability test procedures and augment reference (b) with more detailed stability test procedures for certain pontoon vessels.

2. Directives Affected: References (b) and (c).

3. Discussion:

a. Simplified Stability Test for Monohull Vessels: The Coast guard originally developed the simplified stability proof test currently found in reference (a) in the 1950s. The Coast Guard created this tool for OCMIs to evaluate the stability of monohull small passenger vessels. The Coast Guard wrote the regulations in 46 CFR 178.310 to apply to certain monohull small passenger vessels defined as:

- Less than 65' in length
- Carrying 150 or less passengers
- Carrying no more than 12 passengers on an international voyage
- Having only one hull
- Having no more than 1 deck above the bulkhead deck, not including a pilothouse, and
- If a sailing vessel, meets the restrictions in 46 CFR 178.325.

b. Simplified Stability Test for Pontoon Vessels: The Coast Guard created the pontoon simplified stability proof test currently found in reference (b) for OCMIs to evaluate the stability of lightweight pontoon small passenger vessels. The Coast Guard wrote the regulations in 46 CFR 178.340 to apply to certain pontoon small passenger vessels defined as:

- Less than 65' in length
- Carrying 49 or less passengers
- Operating only on protected waters
- Floating on only 2 separate, fully enclosed symmetric pontoons
- With no machinery or tankage in the pontoons

16711

Subj: EVALUATION OF STABILITY & SUBDIVISION REQUIREMENTS FOR SMALL PASSENGER VESSELS INSPECTED UNDER 46 CFR SUBCHAPTER T

- With only one deck accessible to passengers, and the accessible portion of the deck does not extend outboard of the pontoons at their outermost point, and
- Constructed with the deck no higher than 6 inches above the top of the pontoons.

c. Spacing Calculations for Monohull Vessels: The simplified subdivision bulkhead spacing calculations determine the maximum distance between transverse watertight bulkheads. The Coast Guard designed these regulations to place bulkheads at strategic locations throughout the vessel to limit flooding effects should the vessel become damaged below the waterline. In particular, these regulations ensure that the bulkhead deck will remain above the water if any one compartment floods. In accordance with 46 CFR 179.212, OCMIs shall perform the simplified subdivision bulkhead spacing and freeboard calculations in 46 CFR 179.220, for monohull small passenger vessels less than 65' in length that:

- Carry more than 49 passengers, or
- Are constructed of wood on or after March 11, 2001, and operate on cold water

d. Other Hull Forms: Since the development of the simplified stability proof test and the pontoon simplified stability proof test, we have seen owners use other hull forms for their small passenger vessels. These other hull forms include catamarans, trimarans, and other hybrid multi-hull types. Catamarans differ from pontoon vessels in that the hulls often contain machinery, tankage, and piping, the hulls may be asymmetric, and the hulls are often integral with the deck above. These vessels should not perform the monohull simplified stability proof test or the pontoon simplified stability proof test. These vessels shall submit stability calculations to the Marine Safety Center for review and approval.

4. Applicability: The OCMIs shall apply these guidelines to all Subchapter T vessels that require a stability test, or those whose stability, in the judgment of the OCMI, require an evaluation.

5. Action:

a. OCMIs should use enclosure (1) to determine the appropriate method for evaluating the stability of a small passenger vessel.

b. G-M initiated a review/assessment of the stability test procedures for pontoon vessels after the capsizing of the pontoon vessel LADY D, with the loss of 5 lives. G-MO-1, Marine Safety Center, G-MSE & G-MOC-1 developed enclosure (2). Enclosure (2) augments reference (b) by providing more detailed guidance to OCMI's when performing simplified stability tests on certain pontoon vessels.

c. What if the OCMI questions the stability of the vessel based on the results of the simplified stability test? The vessel owner must provide calculations to the Marine Safety Center showing the vessel meets the applicable stability criteria of 46 CFR Subchapter "S" in each condition of loading and operation.

d. If the vessel fails the applicable simplified stability test, or the simplified subdivision bulkhead spacing calculations, the vessel owner must provide design calculations to the Marine Safety Center showing the vessel meets the applicable stability criteria of 46 CFR Subchapter "S" in each condition of loading and operation.

16711

Subj: EVALUATION OF STABILITY & SUBDIVISION REQUIREMENTS FOR SMALL PASSENGER VESSELS INSPECTED UNDER 46 CFR SUBCHAPTER T

e. The Marine Safety Center will continue to support OCMIs, in particular, by providing technical assistance to determine the applicability of the simplified stability proof test for unusual vessel types.

f. Due to G-M's ongoing review of stability practices, we will not incorporate enclosure (2) into the Coast Guard's Electronic Forms Library at this time. G-MOC will incorporate this guidance into a future revision of the Marine Safety Manual. Additional questions on this subject may be directed to either the Marine Safety Center or COMDT (G-MOC-1).

#

Enclosure: (1) Subdivision/Stability Flowchart
(2) Pontoon Vessel Simplified Stability Test Procedures

Distribution: G-MO-1
G-MSE
Marine Safety Center
Commander, Coast Guard Atlantic Area (Am)
Commander, Coast Guard Pacific Area (Pm)
All District (m) Offices
All Sector/Activities/Marine Safety Offices

Revised September 28, 2004

- SMALL PASSENGER VESSELS -
SIMPLIFIED STABILITY TEST PROCEDURE FOR PONTOON VESSELS ON PROTECTED WATERS

(In accordance with 46 CFR 178.340)

DEPARTMENT OF
HOMELAND SECURITY
U.S. COAST GUARD

Name of Vessel ________________________ Documentation No. _________ Date ______

Owner/Representative ___________________________ Inspector ____________________

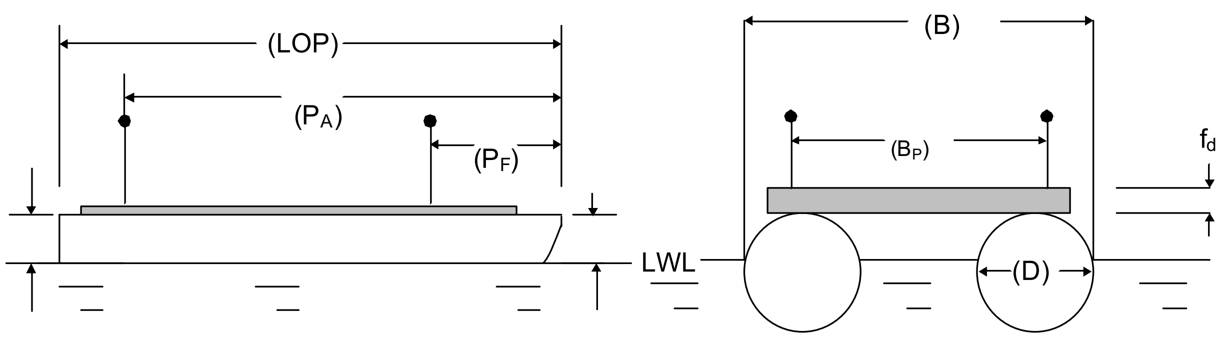
Location ____________________________ Wind: Relative Direction _______ Vel ____ mph

Mooring Arrangement _____________________________________ Route: Protected Only

APPLICABILITY:

This form is to be used ONLY if ALL of the following conditions are met, otherwise contact MSC:

vessel is less than or equal to 65 feet in length
vessel carries 49 or less passengers
vessel operates on protected waters
vessel is a pontoon boat, i.e. fully enclosed pontoons with no machinery or tanks inside
vessel has only two pontoons
vessel has outboard engines
vessel has only one deck and the deck is less than 6 inches above pontoon tops (f_d below)
deck accessible to passengers does not extend beyond pontoons fore/aft and port/stbd
transverse test moment is greater than minimum test moment (see Section (2))



Indicate on above Sketch	Indicate on above Sketch
1) Pontoon length (LOP)	1) Maximum beam (B) to outside of pontoons
2) Distance, from pontoon bow, of furthest fwd location accessible to passengers (P_F)	2) Maximum beam (B_P) accessible to passengers
3) Distance, from pontoon bow, of furthest aft location accessible to passengers (P_A)	3) Distance (f_d) between pontoon tops & top of deck; must be less than 6 inches.
4) Freeboard at bow to pontoon top	4) Pontoon diameter (D) if circular pontoons; Pontoon waterline breadth if wall-sided
5) Freeboard at stern to pontoon top	

The measurements above are to be taken in the loaded condition with trim and heel minimized. Measurements for (LOP) and (B) are to exclude rub rails.

Revised September 28, 2004

(1) TOTAL TEST WEIGHT REQUIRED:

Total test weight must include the weight of passengers *and crew*.

__________ X __140___ = __________ pounds
\# of Pass. Wt/Pass. Pass. Test Wt. (W_P)

__________ X __160___ = __________ pounds
\# of Crew Wt/Crew Crew Test Wt. (W_C)

__________ + __________ = __________ pounds
(W_P) (W_C) Total Test Wt. (W)

Notes:
a) "Total Test Weight" defines only the weight to be moved during the test. Weights used to represent missing equipment or stores shall be considered part of the "loaded condition."
b) The maximum number of passengers shall not exceed the number computed in accordance with 46 CFR 176.113. At no time shall the number of passengers exceed 49.
c) Weight per passenger equals 72.6 kg (160 lbs), except when passenger loads consist of men, women, and children; weight per passenger of 63.5 kg (140 lbs) may be used. Weight per crew member is 72.6 kg (160 lbs).

(2) MINIMUM TEST MOMENT -- SIMPLIFIED:

The calculated test moment (M_{Test}) cannot be less than the simplified minimum test moment (M_{Min1}) as calculated below:

Simplified Minimum Test Moment (M_{Min1}) = __300_lb X __________ = __________ ft-lb
Vsl Length (LOP) (M_{Min1})

Calc. Test Moment (M_{Test}) = __________ X __________ ÷ __2__ = __________ft-lb
Total Test Wt. (W) Pax. Beam (B_P) (M_{Test})

Simplified Minimum Test Moment	Calculated Test Moment
__________ft-lb (M_{Min1})	__________ft-lb (M_{Test})

If (M_{Test}) is greater than or equal to (M_{Min1}) then this simplified test is valid. Skip to section (4) and continue with this test.

If (M_{Test}) is less than (M_{Min1}) then this simplified test may not be valid. Go to the next section to calculate the actual minimum test moment.

Revised September 28, 2004

(3) MINIMUM TEST MOMENT -- CALCULATED:

a) If the calculated test moment is less than the simplified minimum test moment calculated in section (2) above, the actual minimum test moment must be calculated using the wind profile of the vessel.
b) Go to Appendix A to calculate the actual minimum test moment and enter it below.

Minimum Test Moment (from Appendix A)	Calculated Test Moment (from section (2) above)
________________ ft-lb	________________ ft-lb
(M_{Min2})	(M_{Test})

If (M_{Test}) is greater than or equal to (M_{Min2}) then this simplified test is valid. Go to the next section and continue with this test.

If (M_{Test}) is less than (M_{Min2}) then this simplified test is not valid. Stop the test. The owner has the option to conduct a stability test (incline or deadweight survey) and submit calculations to MSC. Contact MSC if you have questions.

(4) VESSEL CONDITION PRIOR TO & DURING TESTS:

a) The test shall be conducted with all tanks ¾ full, ballast onboard and in place, and any non-return valves or flaps on scuppers or deck drains restrained in the open position.
b) The test shall be conducted with the vessel in the full load condition. Any items, such as chairs, coolers, and deck coverings, which are not onboard at the time of the test shall be simulated by the use of weights approximating the weight and location of the missing items. These simulated weights are not to be shifted during any of the following tests.
c) The vessel shall be fully afloat and all mooring lines are to be slack during the test.
d) If the vessel carries passengers on diving excursions, the total weight of diving gear must be included in the loaded condition. Diving gear is assumed to be 36 kg (80 lbs) person.
e) During the loading and moving of test weights, care should be taken if there is any evidence of low stability. This may be assumed to be the case whenever the effect of any added or shifted weight increment is noted to be more than that of the preceding increment of the same size, or when one of the pontoons comes out of the water or is submerged as a result of the heel.
f) Care is to be exercised that the vessel is not heeled excessively either due to weight movement or superimposed roll which could cause the test weights to topple or the ship's gear to become adrift.
g) Before the vessel is heeled, check for open seams, loose hull fittings, etc., which are not normally immersed and which could cause flooding of the vessel.

Revised September 28, 2004

(5) TRANSVERSE STABILITY TEST – DISTRIBUTION OF TEST WEIGHT:

a) Distribute test weights so as to minimize heel and trim.
b) Arrange the test weight so that its vertical center of gravity (VCG) is approximately 76.2 cm (30 inches) above the deck
c) The vertical distribution of the test weight shall be such as to simulate the most unfavorable VCG likely to occur in service.

(6) TRANSVERSE STABILITY TEST – DETERMINATION OF METHOD:

a) If the pontoons have a circular cross section, proceed to Appendix B.
b) If the pontoons are wall-sided, proceed to Appendix C.
c) For all other pontoon shapes, this test may not be applicable – please contact the Marine Safety Center for further guidance.

(7) TRANSVERSE STABILITY TEST – TEST RESULTS:

The vessel passes this test if the vessel meets the requirements of Appendix B or C as applicable.

This vessel **PASSED** the transverse stability test. Continue with Longitudinal Stability Test.

OR

This vessel **FAILED** the transverse stability test. Stop the test. Remove a few passengers (test weight), print a new test form and start the form over, beginning with page 1 of the form.

If the vessel cannot pass this simplified test, the owner has the option to conduct a stability test (incline or deadweight survey) and submit calculations to MSC.
Contact MSC if you have questions.

Revised September 28, 2004

(8) LONGITUDINAL STABILITY TEST – WEIGHT MOVEMENT:

a) The trimming moment shall be obtained by a longitudinal movement of the test weight from Section (1) to the extreme forward or aft position of the deck available to passengers and crew, whichever position is further from the initial position of the load.
b) All other notes from Section (4) shall be observed.

Quantity	Weight per Unit	Subtotal Weight (Quant. x Wt. per Unit)	Distance Moved
	Total Weight		

Check: This should be equal to or greater than the Test Weight from Section (1)

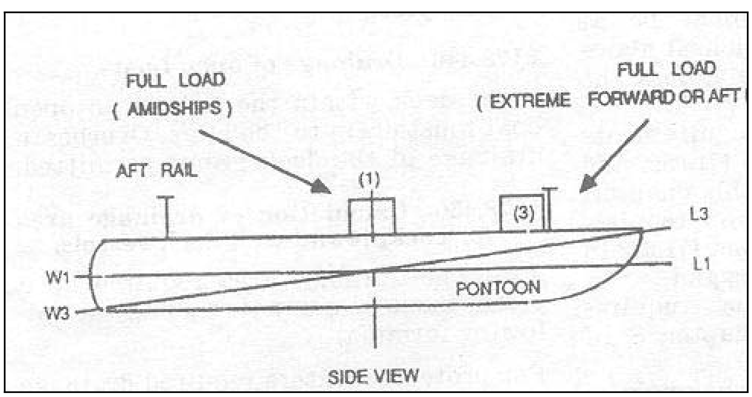
(9) LONGITUDINAL STABILITY TEST – TEST RESULTS:

The vessel passes this test if the tops of the pontoons are not submerged at any location with the weights shifted as indicated above. See the figure below.

This vessel **PASSED** the longitudinal stability test.

This vessel **FAILED** the longitudinal stability test. Stop the test.
Remove a few passengers (test weight) print a new test form and start the form over, beginning with page 1 of the form.

If the vessel cannot pass this simplified test, the owner has the option to conduct a stability test (incline/deadweight survey) and submit calculations to MSC. Contact MSC if you have questions.



46 CFR Figure 178.340(d)(2)

Revised September 28, 2004

(10) GENERAL STABILITY INFORMATION

Tankage:

Tank	Capacity	Approximate Location of CG @ 100% Cap.	
		Aft of Pontoon Bow	Above Top of Keel

Ballast:

Material	Weight	Approximate Location of CG	
		Aft of Pontoon Bow	Above Top of Keel

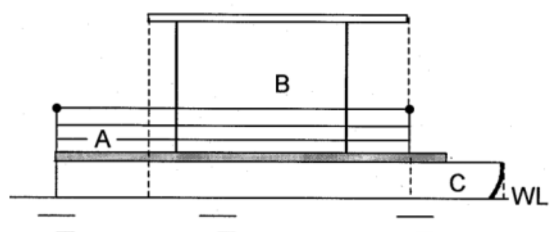
Revised September 28, 2004

APPENDIX A
CALCULATION OF MINIMUM TEST MOMENT BY WIND AREA

(A) HOW TO USE THIS APPENDIX

To determine the calculated minimum test moment, follow the steps below:

a) Block off the profile of the vessel into rectangles using vertical lines starting at the waterline, as shown below. Include passenger railings, canopies, and spotting towers.
b) Measure, on the vessel, the length (L) and height (V) of each rectangle and enter into the table below.
c) Complete the calculations in the table, add the products in the last column and follow the calculations to determine if this test is applicable.



Revised September 28, 2004

APPENDIX A
CALCULATION OF MINIMUM TEST MOMENT BY WIND AREA

(B) SKETCH OF VESSEL PROFILE

Profile

Load Waterline

Scale: 1 square = __________

(C) CALCULATION OF MINIMUM TEST MOMENT

Calculations

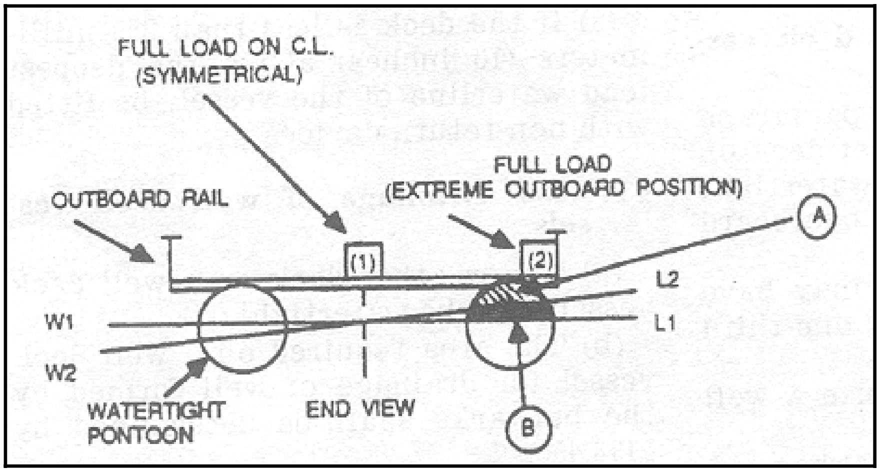
Section	L	V	A (L x V)	H (½ V)	A x H
A					
B					
C					
D					
E					
F					
				Sum of (A x H) =	

Minimum Test Moment (M_{Min2}) = 7.5 lbs/ sq. ft. (Wind Pressure (P)) X ______________ (Sum (A x H)) = _____________ ft-lbs (M_{Min2})

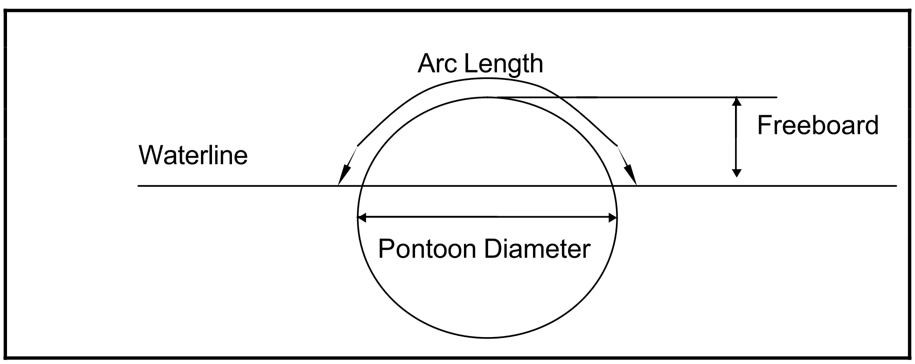
Enter (M_{min2}) into the appropriate block in section (3) of this test form.

Revised September 28, 2004

APPENDIX B
CALCULATION OF AREAS FOR CIRCULAR PONTOONS



46 CFR Figure 178.340(d)(1)



Pontoon Measurement Guide

(A) PONTOON SIZE
Pontoon Diameter = _____________ inches
Pontoon Radius = diameter ÷ 2 = _______________ inches

Revised September 28, 2004

APPENDIX B
CALCULATION OF AREAS FOR CIRCULAR PONTOONS

(B) AREA ABOVE WATERLINE BEFORE WEIGHT MOVEMENT (AREA *A+B*)

Measured arc length = _____________ inches

Ratio 1 = __________ ÷ ______________ x 57.3 = _______________
(arc length) (Pontoon radius) (Ratio 1)

Enter *table* (last two pages of this appendix) with this value and find the closest number in the column labeled *(Ratio 1);* read the value to the right in the column labeled *(Ratio 2)* and enter that number below:

Ratio 2 *(from table)* =_____________

Area = __________ X _____________ X _____________ = [ ] sq in.
(Ratio 2) (Pontoon Radius) (Pontoon Radius) (Area A+B)

(C) WEIGHT MOVEMENT

The heeling moment shall be obtained by a transverse movement of the test weight from Section (1) to the extreme outboard position of the deck available to passengers and crew on the side with the least initial freeboard.

Quantity	Weight per Unit	Subtotal Weight (Quant. x Wt. per Unit)	Distance Moved
	Total Weight		

Check: This should be equal to or greater than the Test Weight from Section (1)

Revised September 28, 2004

APPENDIX B
CALCULATION OF AREAS FOR CIRCULAR PONTOONS

(D) AREA ABOVE WATERLINE AFTER WEIGHT MOVEMENT (AREA *A*)

Measured arc length = _____________ inches

Ratio 1 = __________ ÷ ______________ x __57.3__ = _______________
(arc length) (Pontoon radius) (Ratio 1)

Enter *table* (last two pages of this appendix) with this value and find the closest number in the column labeled *(Ratio 1);* read the value to the right in the column labeled *(Ratio 2)* and enter that number below:

Ratio 2 *(from table)* =_____________

Area = __________ X _____________ X _____________ = [ ] sq in.
(Ratio 2) (Pontoon Radius) (Pontoon Radius) (Area A)

(E) AREA SUBMERGED DUE TO WEIGHT MOVEMENT (AREA *B*)

Area = __________ - _____________ = [ ] sq in.
(Area A+B) (Area A) (Area B)

(F) TEST RESULTS

Pontoon area above waterline after weight movement from Section (D)	Pontoon area submerged due to weight movement from Section (E)
________________ sq. in. (Area A)	________________ sq. in. (Area B)

If (Area A) is greater than or equal to (Area B) then vessel passed test. Continue with Longitudinal Stability Test

If (Area A) is less than (Area B) then stop the test. Remove a few passengers (test weight), print a new test form and start the form over, beginning with page 1 of the form.

Return to Test Form – Section (7)

Revised September 28, 2004

APPENDIX B
CALCULATION OF AREAS FOR CIRCULAR PONTOONS

Ratio 1	Ratio 2	Ratio 1	Ratio 2	Ratio 1	Ratio 2	Ratio 1	Ratio 2
1	0.00000	46	0.04176	91	0.2942	136	0.8395
2	0.00000	47	0.04448	92	0.3032	137	0.8546
3	0.00001	48	0.04731	93	0.3123	138	0.8697
4	0.00003	49	0.05025	94	0.3215	139	0.8850
5	0.00006	50	0.05331	95	0.3309	140	0.9003
6	0.00010	51	0.05649	96	0.3405	141	0.9158
7	0.00015	52	0.05978	97	0.3502	142	0.9314
8	0.00023	53	0.06319	98	0.3601	143	0.9470
9	0.00032	54	0.06673	99	0.3701	144	0.9627
10	0.00044	55	0.07039	100	0.3803	145	0.9786
11	0.00059	56	0.07417	101	0.3906	146	0.9945
12	0.00076	57	0.07808	102	0.4010	147	1.0105
13	0.00097	58	0.08212	103	0.4117	148	1.0266
14	0.00121	59	0.08629	104	0.4224	149	1.0428
15	0.00149	60	0.09059	105	0.4333	150	1.0590
16	0.00181	61	0.09502	106	0.4444	151	1.0753
17	0.00217	62	0.09958	107	0.4556	152	1.0917
18	0.00257	63	0.10428	108	0.4669	153	1.1082
19	0.00302	64	0.10911	109	0.4784	154	1.1247
20	0.00352	65	0.11408	110	0.4901	155	1.1413
21	0.00408	66	0.11919	111	0.5019	156	1.1580
22	0.00468	67	0.12443	112	0.5138	157	1.1747
23	0.00535	68	0.12982	113	0.5259	158	1.1915
24	0.00607	69	0.13535	114	0.5381	159	1.2084
25	0.00686	70	0.14102	115	0.5504	160	1.2253
26	0.00771	71	0.14683	116	0.5629	161	1.2422
27	0.00862	72	0.15279	117	0.5755	162	1.2592
28	0.00961	73	0.15889	118	0.5883	163	1.2763
29	0.01067	74	0.16514	119	0.6012	164	1.2934
30	0.01180	75	0.17154	120	0.6142	165	1.3105
31	0.01301	76	0.17808	121	0.6273	166	1.3277
32	0.01429	77	0.18477	122	0.6406	167	1.3449
33	0.01566	78	0.19160	123	0.6540	168	1.3621
34	0.01711	79	0.19859	124	0.6676	169	1.3794
35	0.01864	80	0.20573	125	0.6813	170	1.3967
36	0.02027	81	0.21301	126	0.6950	171	1.4140
37	0.02198	82	0.22045	127	0.7090	172	1.4314
38	0.02378	83	0.22804	128	0.7230	173	1.4488
39	0.02568	84	0.23578	129	0.7372	174	1.4662
40	0.02767	85	0.24367	130	0.7514	175	1.4836
41	0.02976	86	0.25171	131	0.7658	176	1.5010
42	0.03195	87	0.25990	132	0.7803	177	1.5184
43	0.03425	88	0.26825	133	0.7950	178	1.5359
44	0.03664	89	0.27675	134	0.8097	179	1.5533
45	0.03915	90	0.28540	135	0.8245	180	1.5708

Revised September 28, 2004

APPENDIX B
CALCULATION OF AREAS FOR CIRCULAR PONTOONS

Ratio 1	Ratio 2	Ratio 1	Ratio 2	Ratio 1	Ratio 2	Ratio 1	Ratio 2
181	1.5882	226	2.3319	271	2.86484	316	3.10245
182	1.6057	227	2.3466	272	2.87334	317	3.10495
183	1.6231	228	2.3612	273	2.88169	318	3.10735
184	1.6406	229	2.3758	274	2.88988	319	3.10964
185	1.6580	230	2.3902	275	2.89793	320	3.11183
186	1.6754	231	2.4044	276	2.90582	321	3.11392
187	1.6928	232	2.4186	277	2.91355	322	3.11591
188	1.7102	233	2.4326	278	2.92114	323	3.11781
189	1.7276	234	2.4465	279	2.92858	324	3.11961
190	1.7449	235	2.4603	280	2.93586	325	3.12133
191	1.7622	236	2.4740	281	2.94300	326	3.12295
192	1.7795	237	2.4876	282	2.94999	327	3.12448
193	1.7967	238	2.5010	283	2.95683	328	3.12593
194	1.8139	239	2.5143	284	2.96352	329	3.12730
195	1.8311	240	2.5274	285	2.97006	330	3.12859
196	1.8482	241	2.5404	286	2.97645	331	3.12979
197	1.8653	242	2.5533	287	2.98270	332	3.13092
198	1.8824	243	2.5661	288	2.98880	333	3.13198
199	1.8994	244	2.5787	289	2.99476	334	3.13297
200	1.9163	245	2.5912	290	3.00057	335	3.13389
201	1.9332	246	2.6035	291	3.00624	336	3.13474
202	1.9501	247	2.6157	292	3.01177	337	3.13552
203	1.9669	248	2.6278	293	3.01716	338	3.13625
204	1.9836	249	2.6397	294	3.02241	339	3.13691
205	2.0003	250	2.6515	295	3.02751	340	3.13752
206	2.0169	251	2.6631	296	3.03248	341	3.13807
207	2.0334	252	2.6746	297	3.03732	342	3.13857
208	2.0499	253	2.6860	298	3.04201	343	3.13902
209	2.0663	254	2.6972	299	3.04658	344	3.13943
210	2.0826	255	2.7083	300	3.05101	345	3.13978
211	2.0988	256	2.7192	301	3.05530	346	3.14010
212	2.1150	257	2.7299	302	3.05947	347	3.14038
213	2.1311	258	2.7405	303	3.06351	348	3.14062
214	2.1471	259	2.7510	304	3.06742	349	3.14083
215	2.1630	260	2.7613	305	3.07120	350	3.14100
216	2.1788	261	2.7715	306	3.07486	351	3.14115
217	2.1946	262	2.7815	307	3.07840	352	3.14127
218	2.2102	263	2.7914	308	3.08181	353	3.14137
219	2.2258	264	2.8011	309	3.08511	354	3.14144
220	2.2413	265	2.8107	310	3.08828	355	3.14150
221	2.2566	266	2.8201	311	3.09134	356	3.14154
222	2.2719	267	2.8293	312	3.09429	357	3.14156
223	2.2870	268	2.8384	313	3.09712	358	3.14158
224	2.3021	269	2.8474	314	3.09984	359	3.14159
225	2.3170	270	2.8562	315	3.10245	360	3.14159

Revised September 28, 2004

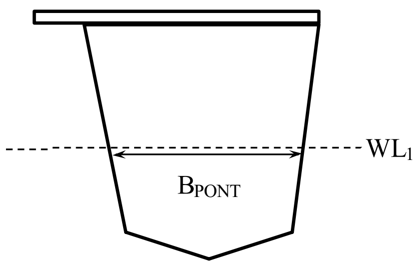
APPENDIX C
CALCULATION OF AREAS FOR WALL-SIDED PONTOONS

(A) APPLICABILITY

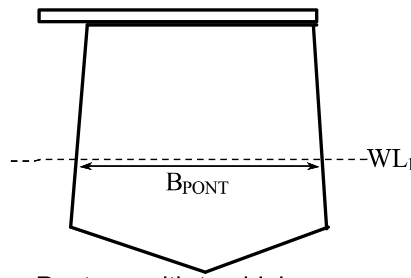
This appendix is applicable for the following shapes with the following restrictions:

1) Rectangular/square pontoons: This test is applicable without restriction.

2) Flared pontoons: This test is applicable for pontoons with flared hulls, not those with tumble-home (see pictures below). The width of the pontoon (B_{PONT}) must be measured **at the waterline**.



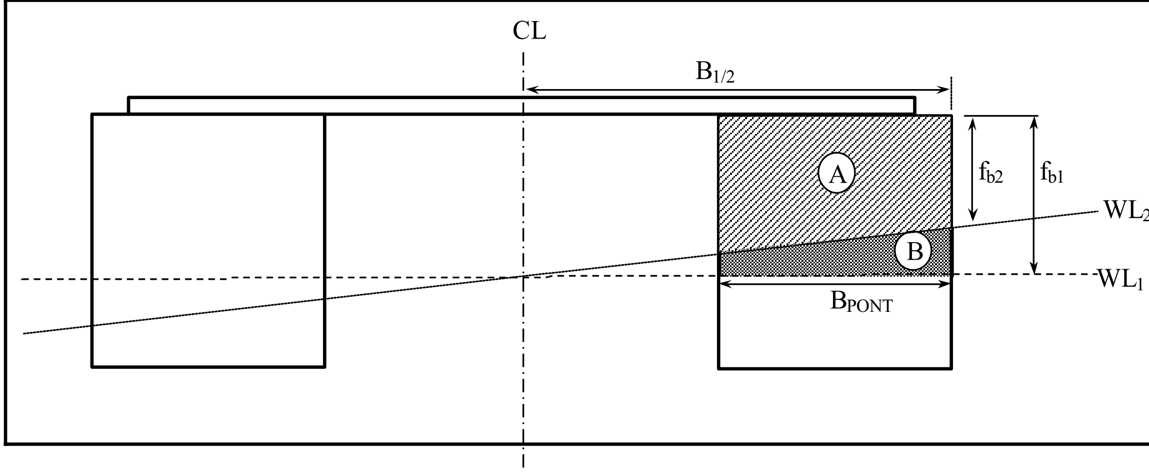
Pontoon with flare
This test is APPLICABLE



Pontoon with tumblehome
This test is NOT APPLICABLE
Submit calculations to MSC

3) Rounded/chine bottoms: This test is applicable as long the chine or turn of the bilge is underwater during the entire transverse stability test. If any part of the chine or turn of the bilge comes out of the water during the test, stop the test.

4) Unusually-shaped pontoons: If the pontoon is not similar to those shown above, contact MSC to determine applicability of pontoon simplified stability test.



Pontoon Measurement Guide

Revised September 28, 2004

APPENDIX C
CALCULATION OF AREAS FOR WALL-SIDED PONTOONS

(B) VESSEL HALF-BEAM

Vessel's ½-beam (centerline to outboard edge of pontoon at pontoon top) measured at same longitudinal location as freeboard measurement = ____________ inches
($B_{1/2}$)

(C) VESSEL CONDITION BEFORE WEIGHT MOVEMENT

Width of pontoon at waterline at same location as freeboard measurement = __________ inches
(B_{PONT})

Check: B_{PONT} must be less than or equal to $B_{1/2}$. If not, this test is not valid. Stop the test.

Freeboard; waterline to top of pontoon = ___________ inches
(fb_1)

(D) WEIGHT MOVEMENT

The heeling moment shall be obtained by a transverse movement of the test weight from Section (1) to the extreme outboard position of the deck available to passengers and crew on the side with the least initial freeboard.

Quantity	Weight per Unit	Subtotal Weight (Quant. x Wt. per Unit)	Distance Moved
	Total Weight		

Check: This should be equal to or greater than the Test Weight from Section (1)

Revised September 28, 2004

APPENDIX C
CALCULATION OF AREAS FOR WALL-SIDED PONTOONS

(E) VESSEL CONDITION AFTER WEIGHT MOVEMENT

Freeboard; waterline to top of pontoon = ___________ inches
(fb_2)

(F) TEST RESULTS

Width Ratio = __________ ÷ ____________ = ____________
(B_{PONT}) ($B_{1/2}$) (WR)

Line 1 = ___1___ - ___________ = ______________
(WR) (Ans 1)

Line 2 = ___2___ - ___________ = ______________
(WR) (Ans 2)

Criteria = __________ X ___________ ÷ __________ = ______________ in.
(fb1) (Ans 1) (Ans 2) (Criteria)

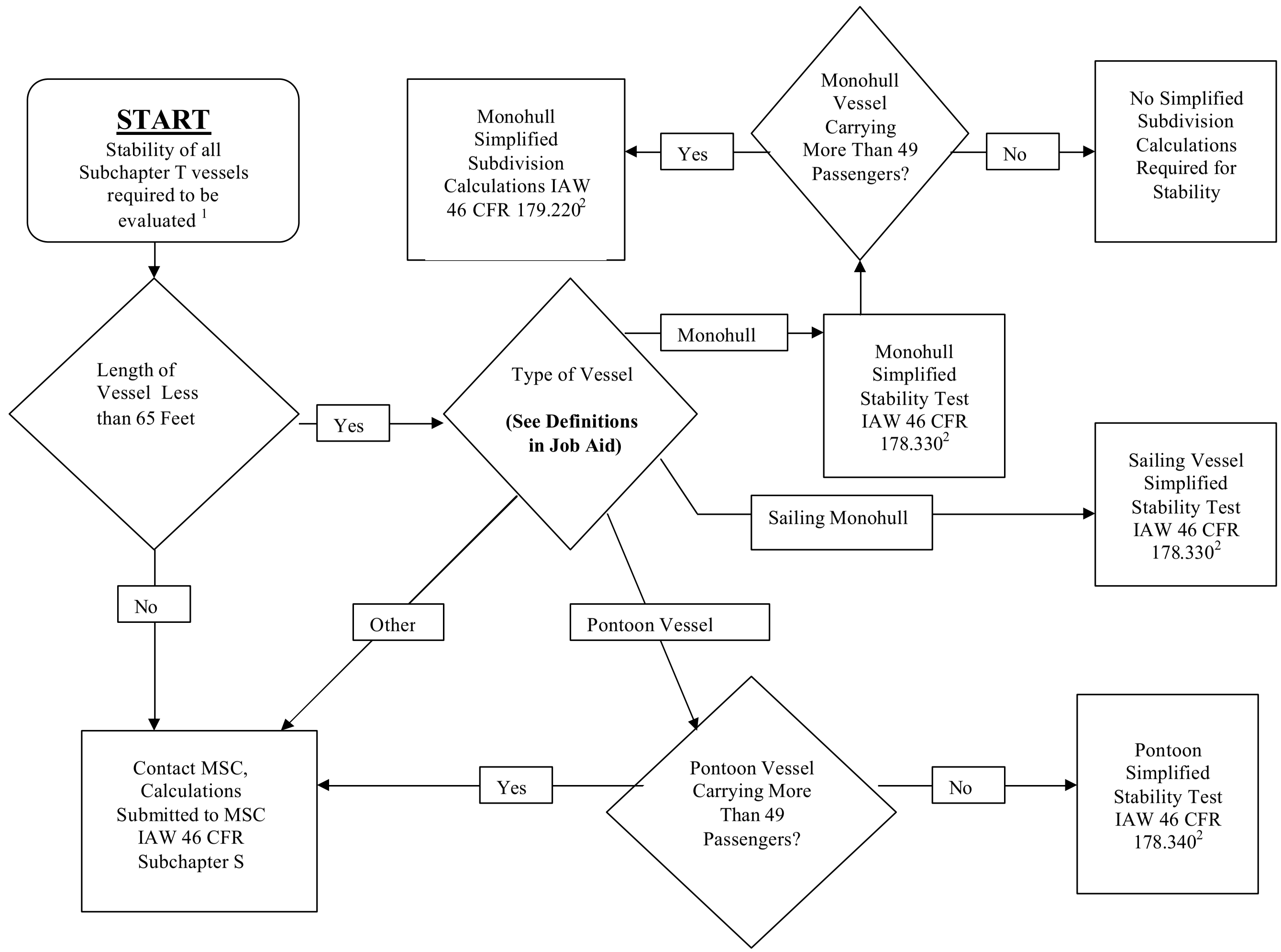
Freeboard taken after weight movement from Section (E)	Result of (Criteria) calculation from line above
________________ in.	________________ in.
(fb_2)	(Criteria)

If (fb_2) is greater than or equal to (Criteria) then vessel passed test. Continue with Longitudinal Stability Test

If (fb_2) is less than (Criteria), then stop the test. Remove a few passengers (test weight), print a new test form and start the form over, beginning with page 1 of the form.

Return to Test Form – Section (7)

Flowchart to Determine the Applicability of Simplified Stability Tests & Simplified Subdivision Bulkhead Spacing Calculations for Small Passenger Vessels Inspected Under 46 CFR Subchapter T



Note 1: Unless specifically waived by the OCMI in accordance with 46 CFR 178.320(c).
Note 2: If the vessel fails the simplified stability test or bulkhead spacing calculations, the vessel must be shown by design calculations submitted to MSC to meet the applicable stability criteria of 46 CFR Subchapter S in each loading and operation.